A FUZZY STRUCTURAL EQUATION MODEL TO ANALYZE RELATIONSHIPS BETWEEN DETERMINANTS OF SAFETY PERFORMANCE IN CONSTRUCTION SITES: DEVELOPMENT OF A SAFETY PERFORMANCE INDEX ASSESSMENT TOOL

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ABSTRACT

A FUZZY STRUCTURAL EQUATION MODEL TO
ANALYZE RELATIONSHIPS BETWEEN DETERMINANTS OF
SAFETY PERFORMANCE IN CONSTRUCTION SITES:
DEVELOPMENT OF A SAFETY PERFORMANCE INDEX
ASSESSMENT TOOL

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The principal aim of this study is to examine the relationships between determinants of safety performance in construction sites. In this study, 168 observable variables and 16 latent dimensions affecting safety performance of construction sites were collected together from detailed literature review, expert opinions and face-to-face interviews with 15 construction safety professionals. Relationships between observed variables and latent dimensions of safety performance of construction sites were studied and a multidimensional safety performance model was proposed. Structural equation modeling (SEM) analysis and testing results showed that, all of the research hypotheses were supported and the proposed multidimensional safety performance model was validated. After validation of the proposed multidimensional safety performance model, the formulation of the safety performance index of construction sites was developed. Case studies were conducted at 11 international construction sites and the results of site safety performance indices were benchmarked. A short (simple) safety performance model was developed as an alternative to the full model (proposed model) to assess safety performance of construction sites. Results showed that short model predicts the safety performance with an acceptable accuracy and requires less time to complete. Finally, a safety performance index assessment software tool for construction sites was proposed by developing a Site Safety Performance (SSP) software and an application for mobile devices based on the empirically validated theoretical model. Top 30 of the observed variables most affecting the safety performance in construction sites were discussed and recommendations to construction safety professionals were provided to improve the safety performance of construction sites.

Keywords: Fuzzy Set Theory (FST), Safety Performance Assessment, Safety Performance Index, Structural Equation Modeling (SEM), Mobile Device Application, Construction Sites, International Construction

ÖZ

İNŞAAT SAHALARININ GÜVENLİK PERFORMANSINI
BELİRLEYEN FAKTÖRLER ARASINDAKİ İLİŞKİLERİN
BULANIK YAPISAL EŞİTLİK MODELLEMESİ ILE ANALİZİ:
BİR GÜVENLİK PERFORMANSI ENDEKSİ
ÖLÇÜM ARACININ GELİŞTİRİLMESİ

Özdemir, Mustafa
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Mayıs 2015, 512 sayfa

Bu çalışmanın temel amacı inşaat sahalarında güvenlik performansının belirleyici faktörleri arasındaki ilişkileri incelemektir. Bu çalışmada, detaylı literatür taraması, uzman görüşleri ve 15 inşaat güvenlik profesyöneli ile yapılan yüz yüze görüşmeler sonucunda, inşaat sahalarının güvenlik performansına etki eden 168 adet gözlemlenen değişken ve 16 adet gizil boyut bir araya getirilmiştir. İnşaat sahalarının güvenlik performansının gözlemlenen değişkenleri ve gizil boyutları arasındaki ilişkiler incelenmiş ve çok boyutlu bir güvenlik performans modeli önerilmiştir. Yapısal eşitlik modellemesi (YEM) analiz ve test sonuçları, araştırma hipotezlerinin tamamının desteklendiğini ve önerilen çok boyutlu güvenlik performans modelinin geçerli olduğunu göstermiştir. Önerilen çok boyutlu güvenlik performans modelinin geçerliliğinin kanıtlanmasından sonra, inşaat sahalarının güvenlik performansı endeksi formülasyonu geliştirilmiştir. 11 adet uluslararası inşaat sahalarında örnek olay çalışmaları yürütülmüş ve sahaların güvenlik performansı endekslerinin ölçüm sonuçları mukayese edilmiştir. Saha güvenlik performansını ölçmek için, tam (önerilen) modele alternatif olarak bir kısa (basit) güvenlik performans modeli geliştirilmiştir. Sonuçlar, kısa modelin, güvenlik performansını kabul edilebilir bir doğruluk düzeyinde tahmin ettiğini ve tamamlanmasının daha kısa bir süre gerektirdiğini göstermiştir. Son olarak, ampirik olarak doğrulanmış teorik modele dayalı olarak, mobil cihazlar için bir Saha Güvenlik Performans (SGP) uygulaması geliştirerek, inşaat sahaları için bir güvenlik performansı endeksi ölçüm yazılımı aracını önerilmiştir. İnşaat sahalarının güvenlik performansını en çok etkileyen 30 adet gözlemlenen değişkenler tartışılmış ve inşaat sahalarının güvenlik performansını geliştirmek için inşaat güvenlik profesyonellerine tavsiyelerde bulunulmuştır.

Anahtar Kelimeler: Bulanik Küme Teorisi (BKT), Güvenlik Performansı Ölçülmesi, Güvenlik Performansı Endeksi, Yapisal Eşitlik Modellemesi (YEM), Mobil Cihaz Uygulaması, İnşaat Sahaları, Uluslararası İnşaat

To My Family

Ayşe Hümeyra, İpek Eslem, Muhammed Emir
Özdemir,

and

Fahriye, Mehmet, Özlem, Ali, Sedef
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LIST OF SYMBOLS AND ABBREVIATIONS

$\cap$	Intersection operator
$\cup$	Union operator
$\overline{}$	Complement operator
ξ	Exogenous Variables
η	Endogenous Variables
χ^2	Chi-square
ρ_c	Composite Reliability
λ	Indicator Loading
θ	Indicated Error
R^2	Squared Multiple Correlations
$\sum$	Summation
$\mu A(x)$	Membership of x into A
ADF	Arbitrary Distribution Free
API	Application Programming Interface
APK	Android Package File
AR	Accident Rate
BOA	Bisector of Area
BOTAŞ	Petroleum Pipeline Corporation
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
COAA	Construction Owners Association of Alberta
COG	Center of Gravity
CPT	Cross Platform Tool
CRM	Customer Relationship Management
CSS	Cascading Style Sheet
CPU	Central Processor Unit

DV	Dependent Variable
EFA	Exploratory Factor Analysis
EMR	Experience Modification Rate
ERB	Embedded RuBy
FIS	Fuzzy Inference System
G1	Scaffoldings and working platforms
G1F1	Lack of installation, operation and disassembly plan for the scaffolding
G1F2	Use of defective and worn fasteners in scaffolding system
G1F3	Improper fastening and supporting against horizontal and vertical forces
G1F4	Leaving rubbish and waste material on scaffoldings and platforms blocking people to pass
G1F5	Use of non-standard guard rails, intermediate rails, toe boards, screens and plankings
G1F6	Absence of gateways having proper system at scaffoldings
G1F7	Failure to take preventive measures (barrier/warning notices) for incomplete/unsafe scaffolds
G1F8	Failure to control before use
G1F9	Failure to hang sign boards indicating the maximum load capacity that scaffoldings can bear at proper and visible places
G1F10	Overloading the scaffoldings and platforms
G1F11	Assembly and disassembly by inexperienced people
G1F12	Failure to use proper personal protective equipment (PPE)
G2	Ladders and stairs
G2F1	To be made of weak and defective material
G2F2	Use of equipment with damaged rungs, arms or connection parts
G2F3	Failure to base on firm and leveled foundation
G2F4	Failure to fix bottom and top parts properly
G2F5	Failure to tag ladders with missing parts
G2F6	Being improper for the job

G2F7	Failure to position at the correct angle
G2F8	Failure to clean enough
G2F9	Failure to position safe distances (Vehicles, mobile cranes and electricity lines etc.)
G2F10	Lack of daily inspection and maintenance
G3	Working at height and protection against falling
G3F1	Failure to plan the work to be done in advance and failure to make the required organizations
G3F2	Failure to place barrier and warning signs for open edges and holes
G3F3	Safety nets and air bags not complying with standards
G3F4	Guardrails, handrails or rails not complying with standards
G3F5	Employee's access to working places by inconvenient means and equipment
G3F6	Failure to take preventive measures against falling of hand tools and other materials
G3F7	Failure to prevent access to the areas subject to falling objects or failure to erect covered gateways
G3F8	Lack of regular inspection and maintenance of safe working equipment used at heights
G3F9	Failure to use proper personal protective equipment (PPE)
G4	Lighting and electricity
G4F1	Failure to supply adequate illumination for working places, passageways and routes
G4F2	Lack of auxiliary illumination system against electricity cuts
G4F3	Use of improper connectors (E.g.: connections with open-ended cables)
G4F4	Lack of utilization of proper residual current device in the main and secondary electricity panels
G4F5	Failure to put the panels, boards, control apparatus, etc. into lockers or cabinets

G4F6	Failure to enclose cabinets, panels and switches in weather-proof enclosures located in wet locations
G4F7	Failure to mark overhead lines and failure to take appropriate measures to prevent contact
G4F8	All of the hardware and connection work done by unauthorized people
G4F9	Failure to place electrical danger posts and warning signs
G4F10	Failure to use proper personal protective equipment (PPE)
G5	Housekeeping, order and tidiness
G5F1	Lack of sufficient space for working areas
G5F2	Failure to provide appropriate places where employees can relax
G5F3	Dumping the garbage negligently and failure to collect the garbage regularly
G5F4	Failure to take preventive measures (barriers/warning signs) for slippery surfaces
G5F5	Lack of fencing the construction site properly to prevent unauthorized entry
G5F6	Leaving waste and materials with sharp and keen edges (E.g.: form with nails) in the working areas
G5F7	Failure to provide isolation tapes and warning notices for plant and equipment temporarily suspended for work execution
G5F8	The sanitary facilities are inadequate and failure to maintain the hygiene requirements
G5F9	Failure to provide sufficient amount of potable water
G5F10	Failure to perform chemical and biological analyzes for potable water
G5F11	Failure to perform measurement and control of harmful dusts, gases, fumes, vapors, vibration, noise, pollution
G5F12	Failure to take necessary measures for protection of workers from too hot and cold
G6	Personal protective equipment (PPE)

G6F1	Lack of having appropriate standards
G6F2	Failure to access easily
G6F3	Failure to provide adequate amounts
G6F4	Lack of correct and proper use by workers
G6F5	Lack of inspection before each use
G6F6	Use of equipment although it is damaged
G6F7	Failure to provide adequate instruction and practical training for use and maintenance
G6F8	Failure to regularly maintain and clean
G6F9	Failure to encourage its use by means of signboard and posters
G7	Fire prevention/protection
G7F1	Lack of adequate number and proper type of fire extinguishers
G7F2	Fire extinguishers are not easily accessible or obstacles are present in front of them
G7F3	Lack of proper and permanent marking for emergency escape routes and exits
G7F4	Lack of uninterrupted and adequate lighting system for emergency escape routes and exits
G7F5	Existing obstacles in front of emergency escape routes and exits making difficult to quit
G7F6	Failure to display emergency plan, procedures, assembly points and emergency telephone numbers at visible positions
G7F7	Lack of adequate/proper number and quality of fire detectors
G7F8	Lack of proper alarm system clearly audible at all points on the site
G7F9	Lack of regular inspection and maintenance of firefighting equipment, detectors and alarm systems
G7F10	Failure to conduct fire drill at regular intervals
G8	Hand/power tools, machinery and devices
G8F1	Improper use and use for purposes other than it is intended

G8F2	Use or operate of tools, machines and devices without security protection inserted
G8F3	Use without making sure of the soundness of the floor and use without fixing
G8F4	Use or operate in damaged condition
G8F5	Use or operate by untrained and unauthorized operators
G8F6	Lack of absence of a trained pointer to guide operator in necessary situations
G8F7	Lack of daily inspection and maintenance
G8F8	Lack of safe work instructions
G8F9	Failure to clean enough
G8F10	Failure to place barricades and warning signs when not in use
G8F11	Failure to position in safe distances (E.g.: people, materials, tools, excavation, slope, underground facility, soft ground, obstacles, and electricity lines)
G8F12	Failure to use proper personal protective equipment (PPE)
G9	Material handling (loading, transport, unloading, handling and storage)
G9F1	Lack of proper planning
G9F2	Transportation by improper vehicles
G9F3	Failure to comply with safe loading limitations
G9F4	Loading/unloading/stacking by unsafe vehicles
G9F5	Failure to design loading places and ramps according to dimensions of the load to be moved
G9F6	Lack of use of forwarding lines that guide loads
G9F7	Failure to remove/disposal of hazardous materials and chemicals by specially trained personnel
G9F8	Storage of hazardous materials and chemicals more than the allowed/exempted amount
G9F9	Absence of legible warning labels on hazardous materials and chemicals

G9F10	Absence of Material safety data sheet (MSDS) belonging to hazardous materials and chemicals
G9F11	Failure to clearly display chemical hazard communication plan
G9F12	Failure to use proper personal protective equipment (PPE)
G10	Traffic and transportation control
G10F1	Lack of correct and regular inspection and maintenance of vehicles
G10F2	Failure to use safety belts
G10F3	Driving vehicle without license
G10F4	Driving vehicle without experience
G10F5	Absence of proper and adequate first aid kit/fire extinguisher tube in vehicles
G10F6	Unclear routes
G10F7	Roads with inadequate width
G10F8	Failure to keep adequate distance between roads (having vehicle traffic) and doors, gates, pedestrian passageways, corridors and stairs
G10F9	Lack of adequate number of direction and warning signs
G10F10	Failure to comply with speed limits
G10F11	Failure to take preventive measures against excavation material spillage and dust
G10F12	Failure to take preventive measures against the entry of unauthorized people to prohibited areas
G11	First aid
G11F1	Absence of trained first aid staff at site
G11F2	Failure to display first aid staff and their contact information at visible positions
G11F3	Lack of adequate number of first aid supplies and equipment
G11F4	Lack of easy to access first aid supplies and equipment
G11F5	First aid supplies and equipment are not ready for use
G11F6	First aid supplies and equipment are not marked appropriately
G11F7	Lack of adequate number of emergency treatment rooms

G11F8	Absence of on-site doctor
G12	Excavation works
G12F1	Inspection and control of excavation works by unauthorized people
G12F2	Failure to locate beforehand underground facilities in excavation areas by using detectors, etc. (E.g.: cable, gas, water, sewer lines)
G12F3	Failure to place proper barriers, railings and warning signs
G12F4	Performing night work without providing adequate lighting
G12F5	Use of unsafe entry and exit gates to access working area
G12F6	Failure to place secured stop blocks preventing the vehicles from falling into excavation area
G12F7	Placing the materials improperly near to the excavation edges
G12F8	Failure to support properly and adequately by performing static calculations of the excavation area (with slab, timber, trench boxes, shoring, lining, etc.)
G12F9	Sloping the excavation area with improper angles
G12F10	Performing excavation works while raining
G12F11	Entry of unauthorized people to the excavation area
G12F12	Failure to use proper personal protective equipment (PPE)
G13	Concrete and formwork
G13F1	Failure to perform form works under the supervision of a competent person
G13F2	Improper design and installation of form panels, supports and struts with respect to the loads on it
G13F3	Use of weak and deformed forms
G13F4	Use of ungrounded electrical vibrator
G13F5	Exposure of reinforcing bars
G13F6	Failure to position the concrete pump properly to the ground that concrete will be poured
G13F7	Failure to fix the concrete pump’s supporting foots to the ground

G13F8	Failure to take account of surrounding facilities while opening and closing pump handles
G13F9	Operating the pump under energy transmission lines without taking precautions
G13F10	Performing work directly below the concrete pouring area
G13F11	Failure to use proper personal protective equipment (PPE)
G14	Welding works
G14F1	Lack of daily control and maintenance of the welding equipment
G14F2	Inadequate ventilation in narrow and confined areas
G14F3	Failure to keep gas cylinders upright and failure to fasten in order not to overturn when shaked
G14F4	Absence of proper type of fire extinguisher nearby
G14F5	Failure to put adequate separation distance between fuels and oxygen
G14F6	Contact oxygen tube with oily hand
G14F7	Failure to take precautions against electrical and gas leakage
G14F8	Use of deformed hoses
G14F9	Welders without license and certificate
G14F10	Failure to use proper personal protective equipment (PPE)
G15	Demolition works
G15F1	Lack of preparation and planning of actions before the start of demolition works
G15F2	Failure to enclose the demolition area and failure to place warning signs
G15F3	Failure to take existing service lines (gas, water, electricity lines, etc.) under control or failure to cut whereas necessary
G15F4	Performing demolition works under the supervision of an incompetent person
G15F5	Failure to remove people, vehicles, materials and equipment enough from the demolition area

G15F6	Failure to take necessary precautions to avoid dust during demolition
G15F7	Failure to transport materials and ruins in a systematical and secured way
G15F8	Failure to perform asbestos powder measurement for structures that may contain asbestos
G15F9	Failure to use proper personal protective equipment (PPE)
G16	Workers
G16F1	Avoiding the use of personal protective equipment intentionally
G16F2	Taking the apparent risks
G16F3	Performing erroneous methods and applications
G16F4	Working without plan and cautiousness
G16F5	Lacking safety consciousness
G16F6	Working without morale
G16F7	Working without permission
G16F8	Use of alcohol and drug
G16F9	The continuous change of workers (Personnel turnover rate is high)
G16F10	Inadequacy of safety trainings
GLS	Generalized Least Squares
GDP	Gross Domestic Product
GPS	Global Positioning System
HTML	Hypertext Markup Language
IDE	Integrated Development Environment
IDV	Independent Variable
IR	Incident Rate
ILO	International Labour Organization
IEA	Injury Exposure Assessment
IPA	iOS Application Archive File
IOS	Iphone Operating System
LOM	Largest of Maxima

MIOSHA	Michigan Occupational Safety and Health Administration
ML	Maximum Likelihood
MLE	Maximum Likelihood Estimate
MLSS	Ministry of Labor and Social Security
MOM	Mean of Maxima
NFI	Normed Fit Index
NNFI	Non-normed Fit Index
OHS	Occupational Health and Safety
PMCS	Project Management and Construction Services
PLS	Partial Least Squares
PPE	Personal Protective Equipment
RCP	Report on Contractors' Performance
RMSEA	Root Mean Square Error of Approximation
RII	Relative Importance Index
RIM	Research in Motion
RTCS	Road, Transport, and Construction Services
SC	Score Card
SDK	Software Development Kit
SEM	Structural Equation Modeling
SHMS	Safety and Health Management System
SME	Safety Management Evaluator
SOM	Smallest of Maxima
SP	Safety performance of construction sites
SSPS	Site Safety Performance System
SPL	Safety Performance Level
SSM	Site Safety Meter
U	Universe of Discourse
UI	User Interface
URL	Uniform Resource Locator
USA	United States of America
WBTC	Works Bureau Technical Circular

WLS	Weighted Least Squares
WWW	World Wide Web
XAP	Application Package File

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the developed as well as developing part of the world, construction industry is considered to be one of the most significant industries in terms of its contribution to Gross Domestic Product (GDP) (Metinsoy 2010), and also in terms of its impact on health and safety of the working population (Farooqui et al. 2008).

The construction industry is one of the most hazardous industrial fields (Mistikoglu et al. 2015; Wu et al. 2015; Fang and Wu 2013) having very high accident rates compared to other sectors (Liu and Tsai 2012; Martínez Aires et al. 2010; Montero et al. 2009; Loosemore and Andonakis 2007; Mitropoulos et al., 2005; Abdelhamid and Everett 2000; Chi and Wu 1997; Hinze and Appelgate 1991). The construction sector employs about 7% of the world's work force, but is responsible for 30–40% of fatalities (Sunindijo and Zou 2012). When the fatal occupational accident statistics of year 2013 in Turkey SSI (2013) were analyzed, the construction sector was found to be the leading sector with a percentage of 38,3%. The following sectors were the transportation and the mining sectors with percentages of 14.4% and 6.2% respectively.

According to the ILO (2010), in the world around 6300 people die each day as a result of accidents or occupational diseases. Annually more than 2.3 million deaths occur as a result of 317 million occupational accidents. Every second a worker suffers an occupational accident. Each death or injury does not only bring suffering to the worker and the worker's family, but also incurs potential delays and significant direct and indirect costs to the projects (Park et al. 2015; Fang and Wu 2013). Direct costs (including medical costs and other workers' compensation insurance benefits) and indirect costs (including claims from injured workers, reduced productivity, job schedule delays, added administrative time, damage to equipment and facilities and low morale) constitutes the larger part of the economic burden (Levitt and Samelson 1993). According to the researches conducted by the International Labour Organization ILO (2010) and ILO (2005), 4% of all global gross domestic product is spent on issues of removals, production interruptions, medical expenses and workers' compensation. According to the estimate of World Bank (2014), the global gross domestic product in the year 2013 amounted to about 75.6 trillion US Dollars. This means, annual global cost resulting from occupational accidents and diseases reaches an approximated value of 3 trillion US Dollars.

Construction projects differs in size, duration, objectives, environment, uncertainty, complexity, deadlines, financial intensity, organization structures, and some other dimensions (Gündüz et al. 2013a; Gündüz et al. 2013b; Keung and Shen 2013; Özdemir 2010; Zou et al. 2007). Construction sites are in a constant state of change; its dynamic, temporary, and decentralized nature dictates frequent inspections (Li et al. 2015; Jannadi and Assaf 1998). Construction site safety is of utmost importance due to nature of construction industry (Park et al. 2015; Priyadarshani et al. 2013). However, in a market driven society, where more concern is for completion of projects to the required quality at minimum time and cost, safety is a secondary concern (Priyadarshani et al. 2013). Although dramatic improvements have taken place in recent decades, prevention strategies lack to achieve higher safety performance and the safety record in the construction industry continues to be one of the poorest (Sousa et al. 2015; Sousa et al. 2014; Reyes et al. 2014; Hinze et al. 2013; Huang and Hinze 2006). Persistent endeavors have been made to promote construction safety, but fatalities still plague the industry (Zhou et al. 2015).

Some construction companies realize the importance of reducing their accident rates not only for humanitarian reasons, but also due to the many financial benefits which flow from the safe conduct of the work. Other companies do not have a strong belief in safety. This has serious repercussions when any unfortunate incidents occur. Good management should always insist that every engineer, supervisor and laborer must be familiar with all basic safety aspects and practices that guard those around the construction sites from accidents and injuries (Jannadi and Assaf 1998).

1.2 Background to the research and problem statement

To control and improve safety performance in construction sites, a key ingredient is an effective measure of safety performance. Both Tarrants (1980) and Laufer (1986) agree that measurement of safety performance is necessary for the following reasons: as a basis for casual factor detection, to locate and identify problem areas, as a basis for trend comparison, to describe the current safety state of an organization, as a basis for predicting future accident problems, as a basis for evaluating accident prevention program effectiveness, as a basis for making decisions regarding the allocation of accident prevention resources, to assess accident costs, to establish long-term accident control, and as a basis for quantifying probable risk of injury or other loss.

Despite the importance of safety performance, Helander (1991) reported that very little research focusing on the construction industry has been performed on this subject. Smith et al. (1999) agrees that there is a need to develop evaluation tools for construction sites to enable them to assess their overall safety performance. The need for measuring safety performance was stipulated in many previous research studies. Several methods on measuring the safety performance on construction sites in the literature have been as follows:

In the “TR Safety Observation Method” (Laitinen et al. 1999), the safety of the work environment and of the work is observed so as to get a sufficiently reliable picture of the current level of safety at the construction site. The observer walks around the construction site and marks down the items of observations. The aim is to have at least one hundred separate items. The items to be observed are grouped into six entries on the measurement form: 1) working, 2) scaffolding and ladders, 3) machinery and equipment, 4) protection against falling, 5) electricity and lighting and 6) order and waste disposal. The observations are marked as ‘correct/incorrect’: the target is marked as correct if it reaches the level of safety standards; otherwise it is marked as incorrect. The safety level of the construction site is a percentage calculated from the number of correct observations divided by the number of total observations. A high safety index as an observation result indicates a low accident rate (Antti-Poika and Laitinen 2004; Laitinen and Paivarinta 2010; Laitinen et al. 1999). TR method has a 2-point scale, where the score is either correct or incorrect, is not sensitive enough to show small changes (Duff 2000), and there is a disadvantage in that the use has only limited possibilities for evaluating hazards. Also the safety level formula of TR method does not take into account the relative importance weights of observed items.

The “Injury Exposure Assessment Method” (IEA) allows an estimation to be made of the risk of an accident occurring during the building implementation phase (Seixas et al. 1998). An observer visits a building site and then scores the various dangers using a checklist, taking into account the presence and degree of protection. The degree of protection is estimated using a weighting between “0” and “10”. A “0” means no protection while “10” stands for full protection. The results are then subsequently added together for each danger. By means of this method, the observer can evaluate whether there may be a risk situation. The IEA method was tested on three building sites and tests showed that there were large and significant differences in the assessments made by different observers. This seems to partly depend on the level of expertise of the observer, so testing randomly chosen observations has its drawbacks. High risk situations which do not happen very often will probably remain undiscovered using this method. Complexity of the IEA method makes it unsuitable for use by construction site employees.

The “Checklist of Safety Indicators” is a method for making safety quantifiable and for using the results to implement improvements so that the safety levels of a company can be increased (Trethewy 2003). In total, 58 indicators were developed for various phases of a building project. These 58 indicators were divided over the phases from design to implementation as follows: drafting and feasibility phase (2 indicators), design and planning phase (10 indicators), selection and invitation-to-tender phase (4 indicators), implementation phase divided into 4 sub-phases (38 indicators), completion, maintenance (4 indicators). The indicators are scored on a six-point scale varying from zero (0) to excellent (5).

“Accident Rate” (AR), “Incident Rate” (IR), “Experience Modification Rate” (EMR) and “Score Card” (SC) methods are some retrospective safety evaluation methods introduced for better safety management. Although Tam and Fung (1998) mentioned use of “AR” is superior to other indices, as the accident rates remain quite constant throughout the years and are easily obtainable, it was regarded as an unsound basis for comparison (Priyadarshani et al. 2013). Accuracy of “IR” depends on how honest a contractor is in revealing accidents, illnesses, fatalities and injuries. “EMR” is the ratio between actual claims filed and expected claims for a particular type of construction (Ng et al. 2005). “EMR” formulae are relatively complex and different versions of calculations exist in practice making it an inappropriate measure of safety performance for all types of companies (Hinze et al. 1995). Retrospective methods are used to understand the causes and to reduce the number of accidents, but the results are limited by imperfections in accident recording and in research and analysis of accident causes (Frijters et al. 2008; Frijters and Swuste 2011). Although there are some benefits from using outcome indicators, their use does not lead to improvement in safety outcomes. The main reason for this is outcome indicators are reactive and well after the event (Ahmad et al. 1999).

As the construction industry is one of the most injury-prone industries worldwide in terms of its unique dynamic, complex and decentralized nature, there is a great need to improve worker safety at construction sites (Li et al. 2015). There is a need for valid and user-friendly assessment methods for construction site safety so that everyone becomes aware of the dangers on the construction site and takes the necessary precautions (Frijters and Swuste 2011; Frijters et el. 2008). Drawing on the above strong endorsement to the need for a safety performance assessment tool, this study will focus on developing and validating a multidimensional safety performance model for construction sites. The determinants of safety performance and relationships between the determinants will be identified and studied. This study will develop an empirically validated theoretical model; then, based on this model, a safety performance index assessment tool will be proposed to improve the construction safety.

1.3 Aim and objectives of the research

The principal aim of this study is to examine the relationships between determinants (observable variables and latent dimensions) of safety performance in construction sites. A multidimensional safety performance model will be developed such that the safety performance determinants will be empirically validated and the relationships between the determinants will be justified. Based on the empirically validated theoretical model, a safety performance index assessment tool will be proposed by developing a site safety performance application for mobile devices. This aim will be realized through the following objectives:

1) To identify the observable variables of safety performance of construction sites,

2) To identify the latent dimensions affecting safety performance of construction sites,

3) To study the relationships between determinants (observable variables and latent dimensions) of safety performance of construction sites,

4) To develop and validate a multidimensional safety performance model,

5) To develop the formulation of the safety performance index of construction sites,

6) To conduct case studies in international construction sites and perform assessment of their safety performance indices and benchmark the results,

7) To develop a short (simple) model as an alternative to the full model to assess safety performance ensuring simplicity, fastness and reasonable accuracy,

8) To propose a safety performance index assessment software tool for construction sites by developing a site safety performance (SSP) software and an application for mobile devices based on the empirically validated theoretical model.

9) To discuss and point out top 30 of the observed variables most affecting the "safety performance of construction sites" and provide recommendations to construction safety professionals.

1.4 Significance and value

This study will adopt a novel approach and represent a safety performance index assessment tool for construction sites based on the empirically validated theoretical model. In this study, an integrated approach will be adopted to incorporate fuzzy set theory into structural equation modeling technique for the analysis of the questionnaire survey data. Proposal of such a tool may have considerable contribution to the literature in construction safety.

1.5 Research methodology

In this study, an exploratory sequential mixed design method will be implemented including successive qualitative and quantitative data collection and analysis phases.

A questionnaire survey will be administered to construction professionals having considerable experience in construction sites as a data collection tool. Data will be collected in linguistic terms as “Low”, “Medium”, and “High”.

The linguistic terms will be defuzzified into concrete numbers by fuzzy set theory which provides strong and significant instruments for the measurement of ambiguities and provides the opportunity to meaningfully represent ambiguous concepts expressed in the natural language. Fuzzy theory is based upon uncertainties where there is an inherent impreciseness and it provides mathematical tools to deal with imprecise, uncertain, and vague data.

Structural equation modeling, a quite strong multivariable analysis technique making possible the evaluation of latent structures, will be used as a research analysis tool. Structural equation modeling will be selected as an analysis and testing tool for the current study due to its unique features over other multivariate techniques (Biddle and Marlin 1987; Myers 1990; Greene 1990; Crowley and Fan 1997; Jackson et al. 2005; Ullman 2006; Bentler 2006; Byrne 2006; Schreiber et al. 2006; Garson 2008; Byrne 2009) such as: 1) SEM provides the researchers with the possibility of studying problems which are neither observable nor quantifiable through the concept of latent variables, 2) SEM allows testing of hypothesis at the construct level with adequate accuracy, 3) While other methods deals only with measured observed variables, SEM enables creation and estimation of latent variables underlying the observed variables, and also examination of their interrelationships, 4) SEM can examine a series of separate, but interdependent, multiple regression equations simultaneously by specifying the structural model, 5) SEM enables the analysis of highly complex models containing diverse types of relations and high number of variables, 6) Direct and indirect causal effects and covariances among variables can be investigated by SEM, instead of studying all variables under the same unique level, 7) Other comparable statistic methods allows only for a limited number of hypothesis to be evaluated, 8) In contrast to ordinary regression methods, SEM takes into consideration of the possible errors in measurement of observed variables. The assumption of perfect measurement of variables was not a realistic approach, it may affect the reliability of analysis and lead to serious inaccuracies, especially when errors are fairly large. Measurement errors could increase model error variance, and lead to biased estimates. This shortcoming of alternative methods is eliminated in SEM to take the effects of poorly measured data into account, 9) SEM takes a confirmatory rather than an exploratory approach to data analysis. This enables the evaluation of hypotheses. Various fit indices and validity/reliability tests are available for examining the compatibility of the developed models and assumed relationships with the sample data. An a priori theoretical model can be tested with empirical data by SEM. In contrast, most other multivariate techniques are descriptive and exploratory in nature, making them less appropriate for model testing.

The validity of the hypotheses and proposed model will be tested by using structural equation modeling based on the collected data. Conforming to the Anderson and Gerbing’s (1988) two-step approach for structural equation modeling, the measurement model will be analyzed separately and prior to the analysis of the structural model, allowing unidimensionality assessments.

1.6 Thesis organization

In Chapter 1, an introduction was made by setting out the background for this thesis and problem statement, stating the aim and objectives, presenting the significance and value, summarizing the methodology adopted to carry out the research, and illustrating the organization of the thesis.

In Chapter 2, the revision of the in-depth literature regarding determinants (observable variables and latent dimensions) of safety performance of construction sites which provided a key role in the development of the thesis will be presented.

In Chapter 3, the research design and research strategies formulated to achieve the objectives of this study will be described and the research methodology implemented in this study will be depicted.

In Chapter 4, the preparation, development and administration of a questionnaire survey (Inquire of latent dimensions and observable variables by taking into account their "probability of an incident" and "impact of an incident" by using 3 point Likert scale (Linguistic scale: low, medium, high)) to construction professionals having considerable experience in construction sites will be explained.

In Chapter 5, a theoretical revision of fuzzy set theory (as an instrument for measurement of ambiguities) will be made, and then, data collection and preparations for analysis by fuzzy operations (Implementation of fuzzification - defuzzification operations (i.e., conversion of linguistic values to numerical values)) will be shown.

In Chapter 6, the proposal of a multidimensional safety performance model and determination of hypotheses based on this model will be presented.

In Chapter 7, the statistical analyses of the acquired data (by IBM SPSS Statistics program) will be performed and results will be demonstrated.

In Chapter 8, a theoretical revision of structural equation modeling (SEM) will be made, and then, analysis of the proposed safety performance model for construction sites by SEM will be explicated.

In Chapter 9, the development of the formulation of the safety performance index of construction sites, and its implementation in case studies will be performed.

In Chapter 10, the development of a Site Safety Performance (SSP) software and application for mobile devices on a cross-platform will be presented.

In Chapter 11, discussions of results will be presented, and recommendations to construction safety professionals will then be provided.

In Chapter 12, conclusions of the study and recommendations to the future studies will be discussed.

CHAPTER 2

LITERATURE REVIEW REGARDING DETERMINANTS (OBSERVABLE VARIABLES AND LATENT DIMENSIONS) OF SAFETY PERFORMANCE *(IN CHRONOLOGICAL ORDER)*

2.1 Introduction

As the process of construction project is very complicated with combination of various parties' endeavors, many stages of work and carrying a long period till the completion, (Puspasari 2006) there have been many determinants of safety performance in construction projects.

In this chapter, the revision of the in-depth literature regarding determinants (observable variables and latent dimensions) of safety performance of construction sites which provided a key role in the development of this thesis will be presented in chronological order. The literature review was carried out through books, journals, conference papers, doctorate theses, master's theses, and the web. The publications related to safety performance were analyzed and studies were presented directly associated with the current research topic. Face-to-face interviews were made with 15 construction safety professionals, including owners, managers, and engineers-supervisors.

As a result, this chapter aims to figure out the determinants (observable variables and latent dimensions) of safety performance of construction sites.

2.2 Referenced studies regarding determinants (observable variables and latent dimensions) of safety performance in construction sites (Initial findings)

Various researchers have examined and identified the determinants of safety performance in construction projects. 25 previous studies directly associated with the current research topic were presented below in chronological order.

1) **Duff, A. R., Robertson, I. T., Phillips, R. A., and Cooper, M. D. (1994). "Improving safety by the modification of behavior." Construction Management and Economics, 12:67-78.**

In examining behavior modification approaches to improving construction safety, Duff et al. (1994) developed a safety audit checklist, used to monitor safety performance of construction sites. Duff et al. (1994) developed a safety audit checklist of 24 items, which functions as a safety performance meter. The meter employed an 11-point rating scale, and the measurement procedure incorporated goal setting and feedback to site personnel in order to affect safety-related behavior. The campaign proved to be successful, and the measuring improved the safety level remarkably at the six sites where observations were made. Safety measures were divided into 4 categories in the checklist.

2) **Jannadi, M. O., and Assaf, S. (1998). "Safety assessment in the built environment of Saudi Arabia." Safety Science, 29: 15-24.**

This paper assessed the safety procedures on a construction job site in Saudi Arabia. Safety on the construction site was assessed by conducting a survey of projects during construction. A standardized checklist was used to conduct the survey. This checklist included those items which are perceived to be important from the safety point of view. These were fire prevention, scaffold/mobile tower, cartridge operated tools, trenching and excavation, housekeeping, sandblasting, power tool machine and equipment, heavy equipment, gas/electric welding, construction formwork, health and welfare, transportation, cranes and lifting devices, compressed gas, air compressors, site safety administration, temporary electricity supplies, and special items. The sites for the study were selected randomly from the Eastern province of Saudi Arabia. The sites were differentiated into large and small projects based on the size, dollar volume and number of workmen employed on the job site. This was done to test whether the level of safety on a construction site was a function of the size of a project. The results of the study indicated that safety levels varied between the large and small projects. Small projects averaged low safety assessment scores in fire prevention, health and welfare and safety administration, while safety assessment scores in large project were consistently high in all different divisions. A Spearman Rho rank correlation of the different divisions was computed and a test of hypothesis was conducted. It was found that both large and small projects generally agree on the ranks of the divisions although they have different safety standards. The checklist of this study included items which were perceived to be important from a safety point of view on the construction site. The checklist consisted of 18 divisions and 98 items distributed among the different divisions.

3) Kvaerner (1998). "Site safety performance system." A system developed by Kvaerner Construction (Building), United Kingdom.

Kvaerner Construction UK Building developed a proactive method of assessment that was called Site Safety Performance System (SSPS). Its purpose was to assist site management in the reduction of accidents on construction sites by encouraging the participation of the workforce in a system of measuring and improving site safety performance and promoting safe behavior at work. This system was applied to all construction contracts, which exceed three months continuous duration or where it is stated in the project plan. Site safety performance was measured in several categories. The site manager would decide which of the categories are applicable to the contract and reference their implementation in the Health and Safety Plan and site induction training. Sufficient trained observers would be appointed to implement and oversee the operation of SSPS. On larger projects more than one observer might be needed. Holiday cover also had to be considered when determining observer quantities. The observer carried out formal observations at intervals not exceeding one week. Observation was done on a snap-shot basis. Using the Safety Performance Sheets for each category, the procedure for measuring site safety performance was as follows: • carry out formal observations; • score proportion of unsafe situations in each category; • calculate raw score; • calculate safety performance level (SPL) using equation supplied; • calculate weekly average SPL; and • compare SPL with target. Once the calculations had been completed, the information should be produced in a suitable format (for example graphs) to give immediate feedback to the workforce on current site safety performance levels and comparison with the agreed targets. Feedback might be direct, involving a gathering together of the workforce or indirect by the use of site safety notice board. Good feedback was essential if the objectives of promoting awareness and persuading individuals to improve their safety-related behavior were to be realized. Site safety performance was measured in 9 categories.

4) **Seixas N.S., Sanders J., Sheppard L., and Yost M. (1998). "Exposure assessment for acute injuries on construction sites: Conceptual development and pilot test". Applied Occupational Environment Hygiene. 13(5): 304-312.**

The Injury Exposure Assessment (IEA) method allowed an estimation to be made of the risk of an accident occurring during the building implementation phase (Seixas et al. 1998). An observer visited a building site and then scored the various dangers using a checklist with ten specific items covering hazards associated with trips, falls from elevations, electrocutions, trenching cave-ins, vehicle-related injuries, and lacerations, taking into account the presence and degree of protection. The degree of protection was estimated using a weighting between 0 and 10. A ‘0’ meaned no protection while ‘10’ standed for fully protection. The results were then subsequently added together for each danger. By means of this method, the observer could evaluate whether there might be a risk situation. The IEA method was tested on three building sites and tests showed that there were large and significant differences in the assessments made by different observers. This seems to partly dependent on the level of expertise of the observer, so testing randomly chosen observations had its drawbacks. High risk situations which do not happen very often would probably remained undiscovered using this method. Another limitation of the study was that it weighted each hazard equally, even though some may be more important than others. Also, complexity of the IEA made it unsuitable for use by construction site employees. IEA method used 10 items in the checklist.

5) **Laitinen H., Marjamaki M., and Paivarinta K. (1999). “The validity of the TR safety observation method on building construction.” Accident Analysis and Prevention. 31: 463-472.**

In the “TR safety observation method” (Laitinen et al. 1999), the safety of the work environment and of the work is observed so as to get a sufficiently reliable picture of the current level of safety at the construction site. The observer walked around the construction site and marked down the items of observations. The aim was to have at least one hundred separate items. The items to be observed are grouped into six entries on the measurement form: working habits, scaffolding and ladders, machines and equipment, protection against falling, electricity and lighting and order and tidiness. The observations were marked as ‘correct/incorrect’: the target was marked as right if it reached the level of safety standards; otherwise it was marked as incorrect. The safety level of the construction site was a percentage calculated from the number of correct observations divided by the number of total observations. A high safety index as an observation result indicated a low accident rate, and vice versa (Laitinen et al.

1999; Antti-Poika and Laitinen 2004; Laitinen and Paivarinta 2010). TR method had a 2-point scale, where the score was either correct or incorrect, was not sensitive enough to show small changes (Duff 2000), and there was a disadvantage in that the use has only limited possibilities for evaluating hazards. Also the safety level formula of TR method did not take into account the relative importance weights of observed items. TR safety observation method used an observation form including 6 safety groups.

6) **WBTC (2000). "Score card for assessment of site safety performance." Works Bureau Technical Circular No. 26/2000, Hong Kong, China. Available at: http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/13/1/c-2000-26-0.pdf (Retrieved: 10.04.2015).**

A Score Card system for assessing contractors' site safety performance was first introduced in 1999 for a trial period of 12 months by Works Bureau Technical Circular (WBTC) No. 12/98 on 36 selected contracts in Hong Kong, China. Following the success of the trial, Works Bureau decided to extend its applications to all works and term contracts carried out by contractors on the "List of Approved Contractors for Public Works" and the "List of Approved Suppliers of Materials and Specialist Contractors for Public Works" except for minor contracts for supply of materials/equipment or laboratory testing etc. WBTC No. 12/96 introduced the revised Report on Contractors' Performance (RCP). "Site Safety" is one of the ten sections to be reported which consists of 6 aspects of performance. An overall "Poor" rating in the Site Safety Section would result in an "Adverse" RCP. In order to enhance the standard of reporting "Site Safety" in the RCP and to ensure a consistent approach be adopted in assessing "Site Safety", the Score Card was developed to provide further guidance to the Reporting Officer for assessing the site safety performance of contractors. The Score Card provided a quantitative approach to assess the safety aspects of performance of contractors. The Score Card for the Assessment of Site Safety

Performance consisted of 6 items (according to their weights included), 40 sub-items and 252 considerations.

7) **Glendon, A. I., and Litherland, D. K. (2001). "Safety climate factors, group differences and safety behavior in road construction." Safety Science, 39(3): 157-188.**

This study investigated the factor structure of safety climate and the relationship between safety climate and safety performance within a road construction organization using a safety climate questionnaire. In this context, a behavior sampling technique was used to evaluate the safety performance of each crew. This method of safety measurement involved observing samples of behaviour at random intervals to determine safety performance. Organizational safety booklets, site supervisors, safety representatives, and employees were consulted to identify key safe and unsafe behaviors within the Main Roads Department of Road, Transport, and Construction Services (RTCS), based in South-East Queensland, Australia, The final list of key behaviors observed was determined from discussions with the Occupational Health and Safety Coordinator and the Principal Construction Technician. The Occupational Health and Safety Coordinator was familiar with the frequency and range of accidents within RTCS (south east), while the Principal Construction Technician visited all job sites frequently and was aware of different safe and unsafe behaviors performed on the job sites. The final list of key behaviors for determining safety performance in this study was composed of 15 items in 4 categories.

8) **Workcover (2001). "Safety Meter, Positive Performance Measurement Tool." A Booklet Published by Workcover, New South Wales, Sydney NSW, Australia. Available at: http://nitinnaik.com/pdf/gen_safetymeter_977.pdf/ (Retrieved: 10.04.2015).**

Safety Meter was a positive performance measurement tool developed to appraise both Occupational Health and Safety (OHS) system implementation and the behavior of employees working within such a system. The tool was adapted by the University of New South Wales from previous research by the Finnish Health and Safety Directorate. Safety Meter was an OHS positive performance measurement and feedback tool. The technique was based on a traditional regular OHS workplace inspection method, but instead records both "compliance" and "noncompliance" to selected categories of measurement. Agreed criteria were used to determine whether performance complies in the categories selected. The result was expressed as a score representing the percentage correct, together with a traditional list of items for rectification. 21 criteria in 6 categories were used in this study to measure safety in the construction industry.

9) **Jannadi, O. A., and Bu-Khamsin, M. S. (2002). "Safety factors considered by industrial contractors in Saudi Arabia." Building and Environment, 37(5): 539-547.**

This paper presented the results of a questionnaire, which was distributed among industrial contractors in the Eastern Province of Saudi Arabia, and formal interviews with the contractors' officials responsible for construction safety. The intent of the survey was to gather data on those significant factors that influence the safety performance of industrial contractors. The sample survey consisted of 28 companies that are involved with large volume of industrial construction activities in the Eastern Province. The paper identified 20 main factors and 85 sub-factors and determined their level of importance based on the survey results and the analysis.

10) **Martin, M. (2002). "SABRE, Construction site safety hazard assessment system: A user's guide." 3rd International Conference on Implementation of Safety and Health on Construction Sites: One Country - Two Systems, 8 - 11 May 2002 Hong Kong, China 13 - 17 May 2002 Beijing, China.**

SABRE is a Site Safety Hazard Assessment System, which is the acronym of Safety Assessment and BRE Company located at Bucknalls Lane, Watford WD25 9XX, United Kingdom) aimed to implement a process on site that pro-actively eliminates the circumstances and situations that may result in an accident. SABRE also aimed to achieve an industry wide Site Safety Hazard Assessment methodology and a tool to enable the supply chain on site to report potential hazards and prevent accidents from happening. This system focused efforts to eliminate safety hazards and encouraged the team on a daily basis to be extra vigilant on hazard spotting knowing that an inspection was due every week and that continued poor performance was to be recorded. The tool allowed issues to be highlighted and scored for discussion with the site team to learn from behavior affecting the score and dissemination to workforce and management alike to raise the profile of safety and hazard assessment. The scoring system aimed to encourage improvement from unacceptable to acceptable levels, as well as acceptable to well-managed, and well managed to excellent. Through recording issues affecting scores, the team could learn about good performance for helping improvement as well as poor performance and reasons why. The system only worked if operatives and management identify and discuss hazards they see on site. The tool was developed to be as generic as possible to allow its implementation across all types of construction projects. Not all categories of assessment may be relevant for every site. SABRE tool used 124 questions in 18 categories to assess safety on site.

11) **Zeng, S. X., Wang, H. C., and Tam, C. M. (2002). "A survey of construction site safety in China." 3rd International Conference on Implementation of Safety and Health on Construction Sites: One Country - Two Systems, 8 - 11 May 2002 Hong Kong, China 13 - 17 May 2002 Beijing, China.**

This study conducted a survey to explore the factors affecting construction site safety. The respondents were asked to provide their opinions on the importance of the factors affecting construction site safety by scores from 1 to 5, where '1' represents the least important and '5' the most important. To determine the relative ranking of the factors, the scores were then transformed to importance indices based on the following formula.

$$\text{Relative importance/difficulty index} = \frac{\sum w}{AN} \qquad \text{(Equation 2.1)}$$

Where w is the weighting given to each factor by the respondents, ranging from 1 to 5, A is the highest weight (i.e. 5 in the study) and N is the total number of samples. Based on Equation 2.1, the relative importance indices (RII) were calculated. In this study, 25 factors affecting the site safety were ranked according to their relative importance indices (RII).

12) **Trethewy, R. W. (2003). "Influences on subcontractor OHS management outcomes in construction." Ph.D. Thesis, University of New South Wales, Australia.**

Trethewy (2003) implemented a site safety environment measurement tool called Site Safety Meter (SSM) to address the need for implementing better safety indicators throughout construction. It acted as a site measurement and feedback tool, which provided a "snapshot" of the overall positive safety performance of a construction site at any fixed point in time. The tool was derived from a literature review of World Best Practice and adapted for Australian conditions from previous work conducted in Finland (Trethewy 2003). The indicator was positive in its approach and provided feedback on both behavioral and structural aspects of a safety system. Consequently the SSM was developed for site safety appraisal by Safety Committees and supervisors. It provided feedback to workers on positive aspects of an individual site; in other words, “what is right”. 12 criteria in 6 categories of issues that relate to safety on a construction site were identified. SSM was then implemented on ten construction sites in Sydney. The sites were all major building sites at various stages of construction and SSM readings were carried out at fortnightly intervals. The person (or group) who undertook the measurement walks around the site looking at all the indicators defined for the six categories recorded both “correct” and “not correct” items categorized under the six site rules. To measure an area, each item observed was scored as “correct” if it met the safety requirements of the defined criteria; otherwise the item was scored as “not-correct”. If the person conducting the measurement was not sure how to score an item, then it was not scored at all. The Site Safety Meter score for a construction site as a whole was calculated by dividing the number of correct items by the total number of items.

13) **McEvoy, P. (2004)."Safety performance on 20 construction sites in Dublin." Master’s Thesis, Dublin Institute of Technology, Dublin, Ireland.**

The aim of this research was to assess factors affecting safety performance on twenty apartment construction sites in Dublin using qualitative and quantitative risk assessment techniques. For this research a site safety observation item checklist was developed to pay particular attention to the category falls from height in construction. A total of 20 construction sites were surveyed in the Dublin area all of which include apartment buildings. All of the sites surveyed were large or medium size construction developments. The sites were all visited within the period from November 2003 to October 2004. Each site survey lasted on average 3 hours. In total there was 60 site item observations made on each of the 20 sites, which amounted to a total of 1,200 site item observations. In this study, a site safety observational checklist was used to measure of the level of safety performance on each construction site visited. This checklist included 60 observational safety items in 8 different headings listed under 3 categories.

14) **Tam, C. M., Zeng, S. X., and Deng Z. M. (2004). "Identifying elements of poor construction safety management in China." Safety Science, 42(7): 569-586.**

Measured by international standards, construction site safety records in China were poor. This paper aimed to examine the status of safety management in the Chinese construction industry, explore the risk-prone activities on construction sites, and identify factors affecting construction site safety. The findings revealed that the behavior of contractors on safety management were of grave concern, including the lack of provision of personal protection equipment, regular safety meetings, and safety training. The main factors affecting safety performance included 'poor safety awareness of top management', 'lack of training', 'poor safety awareness of project managers', 'reluctance to input resources to safety' and 'reckless operations'. The study also proposed that the government should play a more critical role in stricter legal enforcement and organizing safety training programs. This paper identified 25 factors affecting construction site safety.

15) **Berry, C.K., and Bogner J.R. (2005). "Construction contractor weekly safety inspection report." A report published by Department of Labor, North Carolina, USA. Available at: http://www.nclabor.com/osha/etta/exampleprograms/Jobsite_Safety_Checklist_%28long_ver%29.doc (Retrieved: 10.04.2015).**

The North Carolina Department of Labor Operational Safety and Health Consultative Services Bureau prepared a report for on-site surveys. This weekly safety inspection report included 90 items in 19 groups.

16) **Holt, A. S. J. (2006). "Principles of construction safety." Blackwell Science Ltd., Oxford, United Kingdom. Doi: 10.1002/9780470690529.**

Holt (2006) provided a general site checklist for measuring safety performance of construction sites containing 128 safety items in 18 categories.

17) **Naik, N. (2006). "A Study of performance measurement of safety systems in construction." PhD Thesis, University of New South Wales, Australia.**

The aim of the research was to understand the relationship between management process intervention and management process outcomes for safety in the construction industry. Initially a literature review identifying international practices in performance measurement for safety in construction was conducted to review existing safety management processes in partnership with the construction industry representatives. A framework for measuring the performance of safety management processes and related outcomes was developed to stimulate improvement on both projects through the comparison of the performance of the safety management systems and outcomes. This framework was then implemented and established to monitor the performance of the key safety management processes. The successful implementation of the performance measurement framework and the feedback to both stakeholders and subcontractors acted as a good communication tool in creating awareness among subcontractors. It also helped to reduce repetitive hazards, resulting in improved safety outcomes. A statistical analysis found that relatively few injuries were explained by the identified safety hazards. This highlighted the need to look for hazards that were specifically relate to injury occurrence. The research findings identified a method for improving the existing hazard identification process. It was anticipated that such improvements could help to better correlate hazard management processes with the project outcomes for safety in future projects. In this thesis, 12 criteria 6 categories of issues that relate to safety on a construction site were adopted similar to Trethewy (2003).

18) **Farooqui, R. U., Arif, F., and Rafeeqi, S.F.A. (2008). "Safety performance in construction industry of Pakistan." Proceedings of the 1st International Conference on Construction in Developing Countries: Advancing and Integrating Construction Education, Research and Practice (ICCIDC-1 2008), Karachi, Pakistan, pp. 74-87.**

In this paper, safety performance measurement of various construction firms as well as the overall construction industry of Pakistan based on an investigative site survey was conducted. A safety investigation checklist called "Performa" was developed to elicit information about construction safety performance at different sites. This Performa was divided in four categories covering various aspects of site safety measurement. These divisions included: Personnel safety, housekeeping, scaffolding safety, and access to height. Site observation surveys were conducted on 27 sites. As a preference, building construction sites constituting scaffolding operations and working on heights operations were selected. Observations were taken on Mondays and Thursdays. The investigators were instructed to mark the level of agreement to the safety observation statement on the survey instrument on a scale defining the level of safety non-performance. Some snapshots were also taken as evidence of the observations and also for confirming the validity of the observations. The safety performance investigation checklist "Performa" was divided in 4 different categories covering 25 safety performance factors to measure site safety.

19) **Metinsoy, T. (2010). "A method of evaluation of relationship between the safety management and overall safety performance in construction industry." PhD Thesis, Boğaziçi University, Istanbul, Turkey.**

The objective of this study was to propose a new methodology that determines the overall safety performance of the construction site by including safety management performance and on-site safety performance assessment to improve construction safety. The study was particularly based on getting data from the construction sites via developed questionnaire and checklist and creating software called SME (Safety Management Evaluator) working on the basis of fuzzy logic approach that has the capability to evaluate construction contractors' safety management performance and onsite safety performance and notify the safety management deficiencies. The survey data were collected from a sample size of 30 on-going building type construction firms and the responders of the questionnaire were safety managers. Checklist was applied on-site by author in order to observe the real situation of safety. The study included factor analysis and correlation of safety management components and descriptive statistics in order to uncover the correlation patterns among the different variables. The purpose of this evaluation was to establish a base point against which construction contractors can be classified by an index of safety developed for the Turkish construction sector. By developing an index of safety, which includes safety management and on-site performance "defectiveness of the safety management and the overall safety performance of a specific construction company regarding the safety index scale for Turkey" was determined. This study used on-site safety checklist to evaluate on-site safety performance of the construction sites consisting of 43 factors in 11 groups.

20) **CG Schmidt Inc. (2011). "Weekly Safety and Health Inspection Report." Milwaukee, Wisconsin, USA. Available at: http://www.cgschmidt.com/forms-resources/CGS_Weekly_Safety_&_Health_Inspection_Report.pdf (Retrieved: 10.04.2015).**

CG Schmidt Inc. prepared a report for on-site surveys. This weekly safety inspection report included 117 items in 19 groups.

21) **MIOSHA (2011). "Construction Safety & Health Management System (Accident Prevention Program)." Michigan Occupational Safety and Health Administration, Department of Licensing and Regulatory Affairs, Lansing, Michigan, USA. Available at: http://www.michigan.gov/documents/cis_wsh_jobsite_safreview_146959_7.doc (Retrieved: 10.04.2015).**

Michigan Occupational Safety and Health Administration (MIOSHA) provided a tool to give assistance in developing a written Safety and Health Management System (SHMS). A SHMS is also referred to as an Accident Prevention Program. A written accident prevention program is a required part of fulfilling the requirement in MIOSHA Construction Safety Standard (Part 1 General Rules, Rule 114-1) to have an Accident Prevention Program. This tool included some sample language, notes, and additional resources to help companies prepare written accident prevention program. According to Michigan Occupational Safety and Health Administration, an effective SHMS has five primary elements as follows: 1) Management Commitment and Planning, 2) Employee Involvement, 3) Worksite Analysis, 4) Hazard Prevention and Control 5) Safety and Health Training. MIOSHA prepared a job site safety checklist to be used as a tool to assist employers with the inspection of their worksites to identify potential hazards that may be present. This checklist was comprised of 107 safety items in 12 different headings under 5 categories.

22) **PMCS (2012). "The contractor's handbook: Working successfully at the University of Texas at Austin." University of Texas, Austin, USA.**

Throughout all phases of construction performed by the contractors and their sub-contractors, The University of Texas Project Management and Construction Services (PMCS) Department have been monitoring field activities on a regular basis to ensure that work to be conducted in a safe and compliant manner and to maintain a safe work environment while performing construction, renovation and repairs for the university by using a safety observation correct behaviors list and a weekly safety observation checklist. PMCS's safety observation correct behaviors list was comprised of 146 items in 33 groups and safety observation checklist was comprised of 67 factors in 14 groups.

23) **COAA (2013). "Best Practice for Behavior Based Safety Construction Owners Association of Alberta (COAA)." Alberta, Canada. Available at:http://www.coaa.ab.ca/safety/home/behaviorbasedsafetybestpractice.aspx (Retrieved: 10.04.2015).**

COAA prepared a generic checklist composed of 33 items in 8 categories as a guide to observe critical behaviors affecting safety in construction.

24) **L&I (2014a). "Construction site hazards to watch out for." A booklet published by Washington State Department of Labor & Industries, Olympia, Washington D.C., USA. Available at: http://www.lni.wa.gov/Safety/Basics/SmallBusiness/Construction/documents/WhatToWatchoutFor.pdf (Retrieved: 10.04.2015).**

Washington State Department of Labor & Industries (L&I) published a booklet of construction site hazards and situations that resulted in severe injuries or even deaths in the construction sites. This booklet was composed of 15 headings.

25) **Esmaeili, B., Hallowell, M., and Rajagopalan, B. (2015). "Attribute-based safety risk assessment. II: Predicting safety outcomes using generalized linear models." Journal of Construction Engineering and Management, 10.1061/(ASCE)CO.1943-7862.0000981, 04015022.**

Esmaeili et al. (2015) aimed to test the validity of using fundamental attributes of construction work environments that cause injuries to predict safety outcomes. In this paper, struck-by accidents in construction sites were the focus, which are one of the leading causes of construction fatalities. In total, 22 attributes that cause struck-by accidents were identified in construction sites as a predictive measure for safety performance.

2.3 Safety performance determinants (Preliminary findings: 16 latent dimensions and 98 factors affecting safety performance of construction sites with respect to their referenced studies)

According to the preliminary findings of the abovementioned referenced studies, dated between 1994 and 2015, a total of 91 categories, 35 headings, 18 divisions, 45 criteria, 102 groups, 810 items, 185 factors, 124 questions, 40 sub-items, 252 considerations, 22 attributes, 20 main factors, and 85 sub-factors (a grand total of 1.829 determinants) were found as safety performance determinants in construction sites. In this study, abovementioned determinants were screened through expert opinions and least significant findings were removed. A total of 98 observable variables in 16 latent dimensions affecting safety performance of construction sites have been achieved.

Below, observable variables for each dimension will be tabulated.

The preliminary list of 5 observable variables in “Working habits of workers” dimension with respect to their referenced studies are shown in Table 2.1 below.

Table 2.1: The preliminary list of 5 observable variables in "Working habits of workers" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)	
G1: Working habits of workers (1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23)	
1.	*Workers are routinized using the required personal protective equipment / safety equipment correctly (e.g., correct use of helmets, use of ear and eye protection equipment, use of welding goggles). (1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23)*
2.	*Workers are not taking (avoiding) any obvious risk. (5, 8, 12, 14, 16, 17)*
3.	*Workers are having safe positions/actions/practices. (15, 22)*
4.	*Workers are avoiding reckless action. (11, 14)*
5.	*Workers are having safety consciousness. (11, 14)*

The preliminary list of 6 observable variables in "Scaffoldings and working platforms" dimension with respect to their referenced studies are shown in Table 2.2 below.

Table 2.2: The preliminary list of 6 observable variables in "Scaffoldings and working platforms" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)	
	G:2 Scaffoldings and working platforms (1, 2, 3, 5, 6, 8, 9, 10, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 24)
1.	*Scaffolds are of good/proper construction, made of strong and sound materials and properly maintained. (6, 8, 9, 10, 12, 13, 15, 16, 19, 20, 22)*
2.	*Scaffolds are adequately fixed, secured, tied, braced, founded and cleaned by competent person. (6, 8, 9, 10, 12, 13, 15, 16, 17, 18, 19, 20)*
3.	*Safe means of access to scaffolds, such as proper ladders, stairs are provided. (6, 9, 10, 13, 15, 16, 17, 20, 22)*
4.	*Guard rails, intermediate rails, toe boards, screens and plankings are adequately provided and fitted at working platforms. (6, 9, 10, 13, 15, 16, 17, 18, 19, 20, 21)*
5.	*Effective barriers or warning notices are indicated for incomplete or unsafe scaffolds. (6, 16)*
6.	*Scaffolds are inspected periodically and inspection forms are recorded. (6, 15, 16, 20, 21, 22)*

The preliminary list of 5 observable variables in "Ladders and stairs" dimension with respect to their referenced studies are shown in Table 2.3 below.

Table 2.3: The preliminary list of 5 observable variables in "Ladders and stairs" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)	
	G3: Ladders and stairs (4, 5, 6, 8, 9, 10, 12, 13, 15, 16, 17, 18, 19, 20, 22, 24)
1.	*Ladders/stairs are in good condition, made of strong and sound material, inspected and checked for defects before use. (6, 9, 10, 13, 16, 20, 22)*
2.	*Ladders/stairs have level and firm footings. (8, 9, 10, 12, 13, 17, 20, 22)*
3.	*Ladders/stairs are secured against slipping, sliding or falling. (4, 6, 9, 10, 13, 15, 16, 18, 20, 22, 25)*
4.	*Ladders/stairs are placed in a safe place away from moving vehicles, overhead cranes or electricity lines. (10, 20, 22, 24)*
5.	*Ladders/stairs with split or missing rungs are taken out of service. (15, 18, 22)*

The preliminary list of 7 observable variables in "Hand/power tools, machines, equipment and devices" dimension with respect to their referenced studies are shown in Table 2.4 below.

Table 2.4: The preliminary list of 7 observable variables in "Hand/power tools, machines, equipment and devices" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)	
	G4: Hand/power tools, machines, equipment and devices (2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25)
1.	*Hand/power tools, machines, equipment and devices are used properly for the job and within the load limitations. (2, 6, 9, 15, 16, 19, 20, 21, 22, 23)*
2.	*Appropriate safety guards are fitted to hand/power tools, machines, equipment and devices. (2, 6, 8, 9, 10, 15, 16, 19, 20, 21, 22, 23, 25)*
3.	*Hand/power tools, machines, equipment and devices are in good condition, are regularly checked/inspected and have maintenance logs recorded including the date of their repair and have up-to-date test certificates issued by competent authority. (2, 6, 8, 9, 10, 11, 12, 14, 15, 16, 17, 19, 20, 22, 23)*
4.	*Hand/power tools, machines, equipment and devices are operated by trained/licensed personnel only, slingers/banksmen are appointed, adequately trained and assigned as the only persons entitled to give signals to operators, and operator logs are up to date. (2, 6, 8, 9, 10, 11, 14, 15, 16, 19, 20, 21, 22)*
5.	*Hand/power tools, machines, equipment and devices are stored in safe condition at idle time. (2, 6, 8, 9, 15, 16, 18, 19, 20, 21, 22, 23)*
6.	*Hand/power tools, machines, equipment and devices are in a safe distance from people, materials, vehicles, excavations, slopes, underground services, soft grounds, obstructions, power lines, etc. (e.g., power lines are de-energized, removed or relocated at a safe distance) and barricades /warning signs are put in place. (6, 9, 10, 15, 19, 21, 22, 23)*
7.	*Lifting devices are firmly leveled to base and material to be lifted is firmly supported and outriggers are used if needed. (2, 6, 10, 15, 16, 20, 22)*

The preliminary list of 4 observable variables in "Protection against falling" dimension with respect to their referenced studies are shown in Table 2.5 below.

Table 2.5: The preliminary list of 4 observable variables in "Protection against falling" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)
G5: Protection against falling (4, 5, 6, 8, 9, 10, 12, 13, 15, 16, 17, 19, 20, 21, 22, 23, 24, 25)
1. Workers working at low levels are protected from falling objects (e.g., using personal protective equipment). (1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23)
2. Open edges and holes are clearly marked to guard against falls of people and materials. (4, 5, 6, 8, 10, 12, 16, 17, 21, 22)
3. Floor & roof openings, platforms, stairways and runways are equipped with proper railings, handrails, guardrails and covers. (6, 8, 10, 12, 15, 16, 17, 19, 20, 21, 22)
4. Proper personal fall arrest systems and safety nets are used. (10, 13, 15, 16, 19, 21, 22)

The preliminary list of 6 observable variables in "Lighting and electricity" dimension with respect to their referenced studies are shown in Table 2.6 below.

Table 2.6: The preliminary list of 6 observable variables in "Lighting and electricity" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)
G6: Lighting and electricity (2, 4, 5, 6, 8, 9, 10, 12, 15, 16, 17, 19, 20, 21, 22, 23)
1. Adequate illumination is supplied at workplace/passageways/routes. (6, 9, 19, 20, 21)
2. Leads, cords, cables and plugs are free from damage and wirings are adequate, well insulated, and properly grounded. (8, 9, 10, 12, 15, 16, 17, 20, 21, 22)
3. Cabinets, panels and switches located in wet locations are enclosed in weather proof enclosures. (6, 15)
4. Overhead lines are identified and appropriate measures are taken such as removing, diverting or marking the lines to prevent contact. (10, 16, 20)
5. Electrical tools and equipment are inspected, tested and documented by competent personnel according to their testing regime. (2, 6, 9, 12, 16, 17, 20)
6. Electrical danger posts and warning signs are present. (2, 6, 9, 10, 19, 21, 23)

The preliminary list of 9 observable variables in "Housekeeping, order and tidiness" dimension with respect to their referenced studies are shown in Table 2.7 below.

Table 2.7: The preliminary list of 9 observable variables in "Housekeeping, order and tidiness" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)	
	G7: Housekeeping, order and tidiness (1, 2, 5, 6, 7, 8, 9, 10, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24)
1.	*Working areas are clear of tripping hazards, accesses to routes are free from obstruction and adequate width and appropriate signage is provided. (2, 6, 8, 10, 12, 13, 15, 17, 18, 19, 20, 22)*
2.	*Waste bins are not over flowing, adequate number of waste bins are provided for regular collection and disposal. (2, 6, 8, 10, 15, 20, 22)*
3.	*Site is properly fenced off to prevent unauthorized access. (2, 6, 19)*
4.	*Old timbers/wooden planks/sheeting/stripped formwork are striked/denailed. (2, 6, 15, 18, 19, 20)*
5.	*Isolation tapes and warning notices are provided for plant and equipment temporarily suspended for work execution. (2, 6, 19)*
6.	*Supply of potable water and sanitary facilities are adequate and clean. (2, 19, 20, 21)*
7.	*Harmful dusts, fumes, vapors or gases are controlled. (20, 22)*
8.	*All structures being worked on are stable, safe and not overloaded. (6, 10, 16, 18)*
9.	*Noise assessments are conducted and hearing protection zone warnings are placed. (6, 10, 16)*

The preliminary list of 5 observable variables in "Personal protective equipment (PPE)" dimension with respect to their referenced studies are shown in Table 2.8 below.

Table 2.8: The preliminary list of 5 observable variables in "Personal protective equipment (PPE)" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)
G8: Personal protective equipment (PPE) (e.g., helmets, eye protection equipment, hearing protection equipment, respiratory protection equipment, gloves, safety footwear, protective outdoor clothing for adverse environments including dusty, wet, or dirty conditions, reflective safety vests or jackets, fall arrest/restrain equipment, shields.) (1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24)
1. Appropriate and adequate personal protective equipment are provided for workers. (6, 11, 14, 16, 19, 23)
2. Personal protective equipment is worn by workers properly. (7, 8, 9, 10, 12, 13, 15, 17, 18, 20, 22, 23)
3. Adequate instruction and trainings are provided for workers on their use and maintenance. (6, 11, 14)
4. Personal protective equipment is in good condition and is properly maintained. (6, 10, 16, 23)
5. Wearing of personal protective equipment is encouraged with signage and posters. (10, 16)

The preliminary list of 7 observable variables in "Fire prevention/protection" dimension with respect to their referenced studies are shown in Table 2.19below.

Table 2.9: The preliminary list of 7 observable variables in "Fire prevention/protection" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)	
G9: Fire prevention/protection (2, 6, 9, 10, 15, 16, 19, 20, 21, 22, 23)	
1.	*Adequate number & proper type of fire extinguishers is available and accessible. (2, 6, 9, 10, 15, 16, 19, 20, 22)*
2.	*Fire prevention/protection equipment is regularly checked for serviceability and maintenance provided. (6, 9, 15, 22, 23)*
3.	*Fire escape routes kept free of obstructions. (6, 20, 22)*
4.	*Site emergency plan and procedures (including steps required to evacuate the site in case of fire), layout plans (showing fire escape routes), assembly points, and emergency telephone numbers are displayed at visible positions. (6, 15, 16, 19, 20, 21, 22)*
5.	*Controls of ignition sources/fire watches are provided. (2, 9, 20, 22)*
6.	*There are proper storage areas for flammable and combustible wastes, liquids and gases (e.g., LPG and acetylene) with proper signage (e.g., "No Smoking") and these are kept away from direct sunlight. (2, 9, 10, 15, 16, 19, 20, 22)*
7.	*A proper alarm system is present (clearly audible at all points on the site). (10, 16)*

The preliminary list of 8 observable variables in "Excavation/trenching/shoring/earthworks" dimension with respect to their referenced studies are shown in Table 2.10 below.

Table 2.10: The preliminary list of 8 observable variables in "Excavation/trenching/shoring/earthworks" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)
G10: Excavation/trenching/shoring/earthworks (2, 4, 6, 7, 9, 10, 15, 16, 18, 19, 20, 21, 22, 24, 25)
1. Competent person is assigned for inspection and supervision of the excavation works. (6, 15, 16, 19, 20, 21, 22)
2. Underground services are located before excavation and precautionary measures are taken against damages to utilities with the use of detectors, trial pits etc. (6, 10, 15)
3. Proper barriers/warning signs/lights are supplied to the excavation. (2, 6, 15, 16, 18, 21)
4. Safe access/egress ways are provided for excavation. (2, 4, 6, 10, 16, 19, 20, 21, 22)
5. Guard rails or other protection methods are used to prevent people falling into excavation. (7, 10, 16, 21)
6. Properly secured stop blocks are provided to prevent tipping vehicles falling into excavation. (6, 10, 16, 21)
7. Materials are kept away from the edge of the excavation in order to prevent them from falling into excavation and to reduce the likelihood of a collapse of the side into excavation. (6, 10, 15, 16, 20, 21, 22, 25)
8. Adequate/appropriate supporting material is supplied (e.g., sheets, timber, trench boxes, props, etc.) and proper angle of batter (sloping) and shoring is supplied to prevent collapse. (2, 6, 9, 10, 15, 16, 19, 20, 21, 22)

The preliminary list of 5 observable variables in "Concrete formwork/concrete construction" dimension with respect to their referenced studies are shown in Table 2.11 below.

Table 2.11: The preliminary list of 5 observable variables in "Concrete formwork/concrete construction" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)	
G11: Concrete formwork/concrete construction (7, 9, 15, 19, 20, 22, 24)	
1.	*Grounded electrical vibrators are used. (9)*
2.	*Workers are protected from cement dust/concrete spread. (15)*
3.	*Protruding reinforcing rods are covered. (15)*
4.	*Adequate strength timbers are used. (19)*
5.	*Side slope bracings/shorings/supports are properly checked. (9, 19, 20)*

The preliminary list of 5 observable variables in "Gas/electric welding" dimension with respect to their referenced studies are shown in Table 2.12 below.

Table 2.12: The preliminary list of 5 observable variables in "Gas/electric welding" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)	
G12: Gas/electric welding (2, 6, 8, 9, 10, 15, 18, 20, 22)	
1.	*Gas/electric welding equipment is daily inspected. (6, 9, 20)*
2.	*Adequate ventilation is supplied. (9, 19, 22)*
3.	*Gas cylinders are stored and secured upright and gas lines are in good and protected condition. (6, 9, 15, 20, 22)*
4.	*Flammable materials protected and proper separating distance is kept between fuels and oxygen. (15, 20, 22)*
5.	*Fire extinguishers of proper type are held close. (6, 9, 15, 20, 22)*

The preliminary list of 6 observable variables in "Handling and storage of materials" dimension with respect to their referenced studies are shown in Table 2.13 below.

Table 2.13: The preliminary list of 6 observable variables in “Handling and storage of materials” dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)	
	G13: Handling and storage of materials (including hazardous goods and chemicals such as fuels, gas cylinders and other hazardous chemicals, refrigerants, paints, cleansing agents etc.) (2, 6, 7, 9, 10, 11, 14, 15, 16, 20, 21, 22, 23, 24)
1.	*Proper planning is made and adequate number of workers is assigned for handling and storage of materials. (2, 9, 15, 16, 22)*
2.	*Storage of dangerous goods and chemicals does not exceed permitted/exempted quantity. (6, 9, 16, 21)*
3.	*Materials are securely stored/stacked according to safe loading limits (i.e., not overloading the supporting structure) and tag lines are used to guide loads. (9, 10, 15, 16, 20, 21, 22)*
4.	*Hazardous goods and chemicals are removed and disposed by specially trained persons in accordance with statutory requirement. (6, 9, 10, 15, 16)*
5.	*Storage for inflammable materials is provided with suitable fencing and shelter, and fuels, paints, varnishes, lacquers and other volatile painting materials are stored in proper containers with adequate warning labels. (2, 6, 9, 22)*
6.	*Instruction notices/adequate warning labels/treatment procedures are provided on hazardous goods and chemicals. (6, 9, 15)*

The preliminary list of 9 observable variables in “Traffic diversion and transportation control” dimension with respect to their referenced studies are shown in Table 2.14 below.

Table 2.14: The preliminary list of 9 observable variables in "Traffic diversion and transportation control" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)	
	G14: Traffic diversion and transportation control (2, 4, 6, 7, 9, 10, 14, 15, 16, 20, 21, 22, 23, 24, 25)
1.	*Vehicles (Buses/pickups/trucks/other) have regular/proper maintenance and tires, brakes, lights, warning devices are operative. (2, 6, 9, 10, 16, 20, 21, 25)*
2.	*Seat belts are used properly. (2, 9, 15, 20, 22)*
3.	*Operators/drivers are licensed and trained. (2, 6, 9, 20)*
4.	*Weight limits and load sizes are controlled. (20, 21)*
5.	*Adequate and proper first aid equipment/fire extinguishers are available in vehicles. (9, 15)*
6.	*Traffic motion of vehicles, plants and pedestrians are organized and routes are determined. (6, 16, 21)*
7.	*Adequate directional/warning signs are erected for traffic control (e.g., speed limit sign). (6, 9, 15, 16, 21)*
8.	*Precautions are taken to avoid tipping of construction vehicles with the use of markers or stoppers. (6, 10, 16)*
9.	*Dust suppression measures such as regular watering / covering up the excavated materials are taken during transport. (6)*

The preliminary list of 6 observable variables in "First aid facilities" dimension with respect to their referenced studies are shown in Table 2.15 below.

Table 2.15: The preliminary list of 6 observable variables in "First aid facilities" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)
G15: First aid facilities (2, 6, 9, 10, 14, 15, 16, 19, 20, 21)
1. First aiders (people trained in first aid) are available on site and their names and contact numbers are announced. (6, 15, 20)
2. Adequate first aid/medical facilities are present. (2, 9, 10, 14, 15, 16, 19)
3. First aid boxes are provided at site including isolated locations. (6, 9, 20, 21)
4. First aid boxes are regularly checked and provisions are replenished. (6)
5. First aid boxes have first aid instructions on themselves. (6, 20)
6. Workplace doctor is provided at sites where there are 50 or more workmen. (6)

The preliminary list of 5 observable variables in "Demolition works" dimension with respect to their referenced studies are shown in Table 2.16 below.

Table 2.16: The preliminary list of 5 observable variables in "Demolition works" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables* (Referenced Study#)
G16: Demolition works (20, 22)
1. Survey is made prior to start of demolition. (20)
2. Utility service lines are cut off or controlled. (20)
3. Dust suppression measures are used (e.g., watering). (6)
4. Protection of people/materials/equipment is provided against collapse/ruins. (22)
5. Systematic removal of ruins is provided. (20)

The referenced studies for the preliminary list are shown in Table 2.17 below.

Table 2.17: Referenced studies for the preliminary list

Referenced Studies:
1. *Duff, A. R., Robertson, I. T., Phillips, R. A., and Cooper, M. D. (1994). "Improving safety by the modification of behavior." Construction Management and Economics, 12:67-78.*
2. *Jannadi, M. O., and Assaf, S. (1998). "Safety assessment in the built environment of Saudi Arabia." Safety Science, 29: 15-24.*
3. *Kvaerner (1998). "Site safety performance system." A system developed by Kvaerner Construction (Building), United Kingdom.*
4. *Seixas N.S., Sanders J., Sheppard L., and Yost M. (1998). "Exposure assessment for acute injuries on construction sites: Conceptual development and pilot test." Applied Occupational Environment Hygiene. 13(5): 304-312.*
5. *Laitinen H., Marjamaki M., and Paivarinta K. (1999). "The validity of the TR safety observation method on building construction." Accident Analysis and Prevention. 31: 463-472.*
6. *WBTC (2000). "Score card for assessment of site safety performance." Works Bureau Technical Circular No. 26/2000, Hong Kong, China. Available at: http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/13/1/c-2000-26-0.pdf (Retrieved: 10.04.2015).*
7. *Glendon, A. I., and Litherland, D. K. (2001). "Safety climate factors, group differences and safety behavior in road construction." Safety Science, 39(3): 157-188.*
8. *Workcover (2001). "Safety Meter, Positive Performance Measurement Tool." A Booklet Published by Workcover, New South Wales, Sydney NSW, Australia. Available at: http://nitinnaik.com/pdf/gen_safetymeter_977.pdf (Retrieved: 10.04.2015).*

Table 2.17: Referenced studies for the preliminary list (cont.'d)

Referenced Studies:
9. *Jannadi, O. A., and Bu-Khamsin, M. S. (2002). "Safety factors considered by industrial contractors in Saudi Arabia." Building and Environment, 37(5): 539-547.*
10. *Martin, M. (2002). "SABRE, Construction site safety hazard assessment system: A user's guide." 3rd International Conference on Implementation of Safety and Health on Construction Sites: One Country - Two Systems, 8 - 11 May 2002 Hong Kong, China 13 - 17 May 2002 Beijing, China.*
11. *Zeng, S. X., Wang, H. C., and Tam, C. M. (2002). "A survey of construction site safety in China." 3rd International Conference on Implementation of Safety and Health on Construction Sites: One Country - Two Systems, 8 - 11 May 2002 Hong Kong, China 13 - 17 May 2002 Beijing, China.*
12. *Trethewy, R. W. (2003). "Influences on subcontractor OHS management outcomes in construction." Ph.D. Thesis, University of New South Wales, Australia.*
13. *McEvoy, P. (2004)."Safety performance on 20 construction sites in Dublin." Master's Thesis, Dublin Institute of Technology, Dublin, Ireland.*
14. *Tam, C. M., Zeng, S. X., and Deng Z. M. (2004). "Identifying elements of poor construction safety management in China." Safety Science, 42(7): 569-586.*
15. *Berry, C.K., and Bogner J.R. (2005). "Construction contractor weekly safety inspection report." A report published by Department of Labor, North Carolina, USA. Available at: http://www.nclabor.com/osha/etta/exampleprograms/Jobsite_Safety_Checklist_%28long_ver%29.doc (Retrieved: 10.04.2015).*
16. *Holt, A. S. J. (2006). "Principles of construction safety." Blackwell Science Ltd., Oxford, United Kingdom. Doi: 10.1002/9780470690529.*
17. *Naik, N. (2006). "A Study of performance measurement of safety systems in construction." PhD Thesis, University of New South Wales, Australia.*

Table 2.17: Referenced studies for the preliminary list (cont.'d)

Referenced Studies:
18. *Farooqui, R. U., Arif, F., and Rafeeqi, S.F.A. (2008). "Safety performance in construction industry of Pakistan." Proceedings of the 1st International Conference on Construction in Developing Countries: Advancing and Integrating Construction Education, Research and Practice (ICCIDC-1 2008), Karachi, Pakistan, pp. 74-87.*
19. *Metinsoy, T. (2010). "A method of evaluation of relationship between the safety management and overall safety performance in construction industry." PhD Thesis, Boğaziçi University, Istanbul, Turkey.*
20. *CG Schmidt Inc. (2011). "Weekly Safety and Health Inspection Report." Milwaukee, Wisconsin, USA. Available at: http://www.cgschmidt.com/forms-resources/CGS Weekly Safety & Health Inspection Report.pdf (Retrieved: 10.04.2015).*
21. *MIOSHA (2011). "Construction Safety & Health Management System (Accident Prevention Program)." Michigan Occupational Safety and Health Administration, Department of Licensing and Regulatory Affairs, Lansing, Michigan, USA. Available at: http://www.michigan.gov/documents/cis_wsh_jobsite_safreview_146959_7.doc (Retrieved: 10.04.2015).*
22. *PMCS (2012). "The contractor's handbook: Working successfully at the University of Texas at Austin." University of Texas, Austin, USA.*
23. *COAA (2013). "Best Practice for Behavior Based Safety Construction Owners Association of Alberta (COAA)." Alberta, Canada. Available at: http://www.coaa.ab.ca/safety/home/behaviorbasedsafetybestpractice.aspx (Retrieved: 10.04.2015).*
24. *L&I (2014a). "Construction site hazards to watch out for." A booklet published by Washington State Department of Labor & Industries, Olympia, Washington D.C., USA. Available at: http://www.lni.wa.gov/Safety/Basics/SmallBusiness/Construction/documents/WhatToWatchoutFor.pdf (Retrieved: 10.04.2015).*
25. *Esmaeili, B., Hallowell, M., and Rajagopalan, B. (2015). "Attribute-based safety risk assessment. II: Predicting safety outcomes using generalized linear models." Journal of Construction Engineering and Management, 10.1061/(ASCE)CO.1943-7862.0000981, 04015022.*

2.4 Additional referenced studies regarding determinants (observable variables and latent dimensions) of safety performance in construction sites (Additional findings)

In the previous part, according to the findings of a detailed literature review and expert opinions, a total of 98 observable variables in 16 latent dimensions affecting safety performance of construction sites were collected together. After determining the observable variables and latent dimensions affecting safety performance of construction sites, a questionnaire survey form has been prepared (See Chapter 4) and face-to-face interviews about this template have been made with 15 construction safety professionals, including owners, managers, and engineers-supervisors.

Table 2.18 showed the demographics of these interviewees. According to the interview findings, the average length of experience in the construction industry was 21.67 years with a standard deviation of 9.71 years. The parties of interviewees were composed of owners, contractors, and consultants, with the percentage ratios of 53%, 27%, and 20%, respectively. 53% of the interviewees were from private sector, while 47% were from public sector. 73% of the interviewees possessed occupational safety expertise certificate (40% of the interviewees possessed Class A, 13% possessed Class B, 20 % possessed Class C of occupational safety expertise certificate).

Table 2.18: Demographics of interviewees (15 construction safety professionals)

List of Interviewees According to Their Years of Experience in Construction Projects					
Number	**Title**	**Experience (years[a])**	**Sector**	**Party**	**Possession of occupational safety expertise certificate**
1	Manager	42	Private	Contractor	No
2	Engineer-Supervisor	34	Public	Owner	No
3	Owner	30	Private	Owner	Yes, Class A
4	Manager	30	Public	Owner	Yes, Class A
5	Engineer-Supervisor	28	Public	Consultant	Yes, Class A
6	Owner	26	Private	Owner	No
7	Engineer-Supervisor	25	Private	Consultant	No
8	Manager	20	Private	Contractor	Yes, Class A
9	Manager	19	Private	Contractor	Yes, Class C
10	Engineer-Supervisor	16	Public	Owner	Yes, Class C
11	Engineer-Supervisor	15	Public	Owner	Yes, Class B
12	Engineer-Supervisor	12	Public	Owner	Yes, Class C
13	Engineer-Supervisor	10	Public	Owner	Yes, Class A
14	Manager	10	Private	Consultant	Yes, Class B
15	Engineer-Supervisor	8	Private	Consultant	Yes, Class A
[a]: Number of years of experience in the construction industry.					

Taking account of the feedbacks of these construction safety professionals, an additional literature review was made to satisfy the lacking items in the questionnaire template. The findings of this additional literature review were demonstrated in this part. Additional 6 studies directly associated with the current research topic were presented below in chronological order.

26) **Labor Department (2004). "Guidance notes on health hazards in construction work." Occupational Safety and Health Branch, Labor Department, Hong Kong, China. Available at: http://www.labour.gov.hk/eng/public/oh/OHB82.pdf (Retrieved: 10.04.2015).**

Occupational Safety and Health Branch, Labor Department published a guide intending to give a list of possible health hazards in the construction industry which may be used by contractors and concerned persons to identify the health hazards that may be present in their sites and to adopt appropriate preventive measures. According to this guide, health hazards in the construction industry can be grouped as chemical hazards, physical hazards and ergonomic hazards. This guide included 11 health hazard items in 3 groups in the construction industry.

27) **TCH Safety (2006). "Construction site risk assessment tool." Penzance, Cornwall, United Kingdom. Available at: http://www.tchsafety.co.uk/product_pdfs/construction%20site.pdf (Retrieved: 10.04.2015).**

TCH Safety (Temple Court Health and Safety) Company prepared the "Construction site risk assessment tool" to assess the construction health and safety. This tool was comprised of 152 questions in 19 groups.

28) **Safety Culture Company (2012). "Construction hazard identification risk assessment audit tool (iAuditor)." A mobile application and checklist developed and published by Safety Culture, Garbutt, Townsville, Queensland, Australia. Available at: http://www.safetyculture.io/iauditor and http://www.auditforms.net/Workplace%20Inspections/workplace%20inspection%20checklist.pdf (Retrieved: 10.04.2015).**

Safety Culture Company developed a mobile application called "iAuditor" for mobile devices working on iOS and android platforms. This application included a checklist for construction hazard identification and risk assessment audit. This checklist was comprised of 92 questions in 15 groups.

29) **MLSS (2013). "Occupational health and safety regulation for construction works." Ministry of Labor and Social Security, Ankara, Turkey. Available at: http://www.csgb.gov.tr/csgbPortal/ShowProperty/WLP%20Repository/isggm/dosyalar/yapi_isleri_yonetmelik (Retrieved: 10.04.2015).**

Ministry of Labor and Social Security (MLSS) published a bylaw, "Occupational health and safety regulation for construction works" according to the 92/57/EEC Council Directive on the implementation of minimum safety and health requirements at temporary or mobile construction sites. According to this regulation, the minimum general requirements for construction sites were listed as 70 items under 24 headings.

30) **L&I (2014b). "Construction safety inspection checklist." A booklet published by Washington State Department of Labor & Industries, Olympia, Washington D.C., USA. Available at: http://www.lni.wa.gov/Safety/Basics/SmallBusiness/Construction/documents/SelfInspectionChecklist.doc (Retrieved: 10.04.2015).**

Washington State Department of Labor & Industries (L&I) developed a checklist for construction safety inspection. This weekly self-inspection checklist was comprised of 41 factors in 9 groups.

31) **Li, H., Lu, M., Hsu, S. C., Gray, M., Huang, T. (2015). "Proactive behavior-based safety management for construction safety improvement." Safety Science, ISSN 0925-7535, http://dx.doi.org/10.1016/j.ssci.2015.01.013, 75, 107-117.**

Li et al. (2015) proposed a proactive behavior-based safety (PBBS) approach to improve construction safety which combines traditional behavior-based safety management with novel information technology called the Proactive Construction Management System (PCMS), which was developed by the authors and the construction virtual prototyping laboratory (CVPL) of the Hong Kong Polytechnic University. According to Li et al. (2015), PCMS can be used to detect three types of dangers including (1) falling of a person from heights, (2) striking against or being struck by moving objects, and (3) being struck by moving vehicles. In this study, 10 critical worker behaviors were identified and grouped into 4 categories for the assessment of safety performance of construction sites.

2.5 Safety performance determinants (Final list: 16 latent dimensions and 168 observable variables affecting safety performance of construction sites w.r.t. their referenced studies)

In the previous part, taking account of the feedbacks of 15 construction safety professionals, an additional literature review was made to satisfy the lacking items in the questionnaire template. Accordingly, additional 6 studies directly associated with the current research topic, dated between 2004 and 2015, were presented in the previous part.

As a result, with reference to 31 studies directly associated with the current research topic, dated between 1994 and 2015, a total of 91 categories, 59 headings, 18 divisions, 45 criteria, 148 groups, 891 items, 226 factors, 368 questions, 40 sub-items, 252 considerations, 22 attributes, 10 behaviours, 20 main factors, and 85 sub-factors (a grand total of 2.279 determinants) were listed as safety performance determinants in construction sites in Table 2.19.

2.279 determinants were reconsidered through expert opinions and least significant findings were removed. Finally, a total of 168 observable variables in 16 latent dimensions affecting safety performance of construction sites were collected together.

Below, observable variables for each dimension will be tabulated.

The final list of 12 observable variables in “Scaffoldings and Working Platforms” dimension with respect to their referenced studies were shown in Table 2.20 below.

Table 2.19: Safety Performance Determinants in Construction Sites

Ref. Study#	category	heading	division	criteria	group	item	factor	question	sub-item	consid.	attribute	behavior	main fac.	sub-factor
1	4													
2			18			98								
3	9													
4						10								
5					6									
6						6			40	252				
7	4					15								
8	6			21										
9													20	85
10	18							124						
11							25							
12	6			12										
13	3	8				60								
14							25							
15					19	90								
16	18					128								
17	6			12										
18	4						25							
19					11		43							
20					19	117								
21	5	12				107								
22					47	146	67							
23	8					33								
24		15												
25											22			
26					3	11								
27					19			152						
28					15			92						
29		24				70								
30					9		41							
31	4											10		
TOTAL	**95**	**59**	**18**	**45**	**148**	**891**	**226**	**368**	**40**	**252**	**22**	**10**	**20**	**85**
Grand TOTAL	**2.279**													

Table 2.20: The final list of 12 observable variables in "Scaffoldings and Working Platforms" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G1: SCAFFOLDINGS AND WORKING PLATFORMS (1, 2, 3, 4, 5, 6, 8, 9, 10, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27, 28, 30)	
G1F1.	*Lack of installation, operation and disassembly plan for the scaffolding. (22, 23)*
G1F2.	*Use of defective and worn fasteners in scaffolding system. (6, 12, 16, 19, 20, 22, 27)*
G1F3.	*Improper fastening and supporting against horizontal and vertical forces. (2, 8, 12, 13, 16, 18, 19, 20, 21, 22, 27, 29)*
G1F4.	*Leaving rubbish and waste material on scaffoldings and platforms blocking people to pass. (4, 8, 13)*
G1F5.	*Use of non-standard guard rails, intermediate rails, toe boards, screens and plankings. (2, 6, 9, 10, 12, 13, 15, 16, 18, 19, 20, 21, 22, 27, 29)*
G1F6.	*Absence of gateways having proper system at scaffoldings. (2, 19, 21, 22, 29)*
G1F7.	*Failure to take preventive measures (barrier/warning notices) for incomplete/unsafe scaffolds. (6, 10, 16, 22, 23, 27, 28)*
G1F8.	*Failure to control before use. (15, 16, 22, 26, 27, 29)*
G1F9.	*Failure to hang sign boards indicating the maximum load capacity that scaffoldings can bear at proper and visible places. (19, 22)*
G1F10.	*Overloading the scaffoldings and platforms. (13, 16, 27, 28)*
G1F11.	*Assembly and disassembly by inexperienced people. (8, 9, 12, 16, 19, 20, 21, 27, 28)*
G1F12.	*Failure to use proper personal protective equipment (PPE). (13, 18, 20, 21, 22, 29)*

The final list of 10 observable variables in "Ladders and stairs" dimension with respect to their referenced studies are shown in Table 2.21 below.

Table 2.21: The final list of 10 observable variables in “Ladders and stairs” dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G2: LADDERS AND STAIRS (4, 6, 8, 9, 10, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 24, 27, 28, 30)	
G2F1.	*To be made of weak and defective material. (6, 16, 17, 21, 22, 27)*
G2F2.	*Use of equipment with damaged rungs, arms or connection parts. (13, 17, 18, 20, 21, 27, 28, 30)*
G2F3.	*Failure to base on firm and leveled foundation. (10, 13, 18, 20, 21, 22, 27, 28)*
G2F4.	*Failure to fix bottom and top parts properly. (6, 8, 10, 12, 13, 15, 17, 18, 20, 21, 27, 28, 30)*
G2F5.	*Failure to tag ladders with missing parts. (12, 15, 22, 23)*
G2F6.	*Being improper for the job. (13, 15, 16, 18, 19, 20, 21, 22, 27, 28, 30)*
G2F7.	*Failure to position at the correct angle. (6 ,8 ,12, 17, 21, 22, 27)*
G2F8.	*Failure to clean enough. (6, 8, 13, 20, 21, 22, 27)*
G2F9.	*Failure to position safe distances (Vehicles, mobile cranes and electricity lines etc.). (10, 22, 29)*
G2F10.	*Lack of daily inspection and maintenance. (16, 20, 22, 29)*

The final list of 9 observable variables in “Working at height and protection against falling” dimension with respect to their referenced studies are shown in Table 2.22 below.

Table 2.22: The final list of 9 observable variables in "Working at height and protection against falling" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G3: WORKING AT HEIGHT AND PROTECTION AGAINST FALLING (1, 3, 4, 5, 6, 8, 9, 10, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 31)	
G3F1.	*Failure to plan the work to be done in advance and failure to make the required organizations. (9, 22, 23, 27, 29)*
G3F2.	*Failure to place barrier and warning signs for open edges and holes. (4, 5, 6, 8, 10, 12, 15, 17, 20, 21, 22, 26, 28, 29, 31)*
G3F3.	*Safety nets and air bags not complying with standards. (9, 15, 19, 21, 22, 27, 29)*
G3F4.	*Guardrails, handrails or rails not complying with standards. (6, 8, 9, 10, 13, 15, 16, 18, 19, 20, 21, 22, 26, 27, 29, 30)*
G3F5.	*Employee's access to working places by inconvenient means and equipment. (13, 15, 16, 17, 18, 27, 29)*
G3F6.	*Failure to take preventive measures against falling of hand tools and other materials. (10, 15, 16, 18, 21, 22, 25, 27, 29)*
G3F7.	*Failure to prevent access to the areas subject to falling objects or failure to erect covered gateways. (4, 15, 16, 21, 22, 26, 27, 29)*
G3F8.	*Lack of regular inspection and maintenance of safe working equipment used at heights. (16, 19, 21, 29)*
G3F9.	*Failure to use proper personal protective equipment (PPE). (8, 12, 13, 15, 16, 17, 20, 21, 22, 27, 29, 30)*

The final list of 10 observable variables in "Lighting and electricity" dimension with respect to their referenced studies are shown in Table 2.23 below.

Table 2.23: The final list of 10 observable variables in "Lighting and electricity" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G4: LIGHTING AND ELECTRICITY (2, 4, 5, 6, 8, 9, 10, 12, 15, 16, 17, 19, 20, 21, 23, 24, 27, 28, 29)	
G4F1.	*Failure to supply adequate illumination for working places, passageways and routes. (6, 8, 9, 10, 16, 19, 20, 21, 25, 27, 28, 29)*
G4F2.	*Lack of auxiliary illumination system against electricity cuts. (9, 20, 21, 26, 29)*
G4F3.	*Use of improper connectors (E.g.: connections with open-ended cables). (2, 4, 6, 8, 10, 12, 15, 16, 17, 19, 20, 21, 22, 27, 28, 29)*
G4F4.	*Lack of utilization of proper residual current device in the main and secondary electricity panels. (2, 4, 12, 15, 16, 17, 19, 21, 22, 27, 28, 29)*
G4F5.	*Failure to put the panels, boards, control apparatus, etc. into lockers or cabinets. (15, 19, 21, 22, 29)*
G4F6.	*Failure to enclose cabinets, panels and switches in weather-proof enclosures located in wet locations. (2, 6, 10, 12, 15, 20, 28, 29)*
G4F7.	*Failure to mark overhead lines and failure to take appropriate measures to prevent contact. (16, 19, 20, 21, 22, 23, 27, 28)*
G4F8.	*All of the hardware and connection work done by unauthorized people. (6, 16, 19, 27, 29)*
G4F9.	*Failure to place electrical danger posts and warning signs. (2, 9, 19, 20, 21, 22, 27, 29)*
G4F10.	*Failure to use proper personal protective equipment (PPE). (20, 21, 22, 29)*

The final list of 12 observable variables in "Housekeeping, order and tidiness" dimension with respect to their referenced studies are shown in Table 2.24 below.

Table 2.24: The final list of 12 observable variables in "Housekeeping, order and tidiness" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G5: HOUSEKEEPING, ORDER AND TIDINESS (1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 27, 28, 29, 30)	
G5F1.	*Lack of sufficient space for working areas. (8, 10, 15, 16, 20, 23, 29)*
G5F2.	*Failure to provide appropriate places where employees can relax. (6, 9, 10, 16, 19, 27, 28, 29)*
G5F3.	*Dumping the garbage negligently and failure to collect the garbage regularly. (2, 6, 8, 12, 13, 15, 16, 17, 18, 20, 21, 22, 27, 29)*
G5F4.	*Failure to take preventive measures (barriers/warning signs) for slippery surfaces. (4, 9, 22, 29)*
G5F5.	*Lack of fencing the construction site properly to prevent unauthorized entry. (2, 6, 10, 15, 16, 19, 21, 22, 27, 29)*
G5F6.	*Leaving waste and materials with sharp and keen edges (E.g.: form with nails) in the working areas. (2, 6, 8, 15, 17, 18, 19, 20, 25, 29)*
G5F7.	*Failure to provide isolation tapes and warning notices for plant and equipment temporarily suspended for work execution. (19, 20, 22, 23, 26)*
G5F8.	*The sanitary facilities are inadequate and failure to maintain the hygiene requirements. (2, 9, 10, 15, 16, 19, 20, 21, 27, 29, 30)*
G5F9.	*Failure to provide sufficient amount of potable water. (6, 9, 10, 15, 16, 19, 21, 21, 27, 28, 29, 30)*
G5F10.	*Failure to perform chemical and biological analyzes for potable water. (28, 29)*
G5F11.	*Failure to perform measurement and control of harmful dusts, gases, fumes, vapors, vibration, noise, pollution. (6, 15, 16, 20, 22, 26, 27, 28, 29)*
G5F12.	*Failure to take necessary measures for protection of workers from too hot and cold. (2, 19, 20, 25, 26, 29)*

The final list of 9 observable variables in "Personal protective equipment (PPE)" dimension with respect to their referenced studies are shown in Table 2.25 below.

Table 2.25: The final list of 9 observable variables in "Personal protective equipment (PPE)" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G6: PERSONAL PROTECTIVE EQUIPMENT (PPE) (1, 2, 3, 6, 7, 8, 9, 10, 11, 14, 15, 16, 17, 19, 20, 22, 23, 24, 28, 29, 30, 31)	
G6F1.	*Lack of having appropriate standards. (6, 11, 14, 16, 21, 22, 23, 28)*
G6F2.	*Failure to access easily. (22, 23)*
G6F3.	*Failure to provide adequate amounts. (9, 11, 14, 16, 19, 22, 23, 28, 30)*
G6F4.	*Lack of correct and proper use by workers. (10, 11, 14, 17, 21, 21, 22, 23, 28)*
G6F5.	*Lack of inspection before each use. (10, 16, 22, 28)*
G6F6.	*Use of equipment although it is damaged. (16, 22, 30)*
G6F7.	*Failure to provide adequate instruction and practical training for use and maintenance. (6, 16, 22, 28)*
G6F8.	*Failure to regularly maintain and clean. (6, 16, 22, 23, 28, 30)*
G6F9.	*Failure to encourage its use by means of signboard and posters. (6, 9, 10, 20, 21, 22)*

The final list of 10 observable variables in "Fire prevention/protection" dimension with respect to their referenced studies are shown in Table 2.26 below.

Table 2.26: The final list of 10 observable variables in "Fire prevention/protection" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G:7 FIRE PREVENTION/PROTECTION (2, 6, 9, 10, 15, 16, 19, 20, 22, 23, 27, 28, 29)	
G7F1.	*Lack of adequate number and proper type of fire extinguishers. (2, 6, 9, 10, 15, 22, 29)*
G7F2.	*Fire extinguishers are not easily accessible or obstacles are present in front of them. (2, 10, 16, 19, 20, 22, 29)*
G7F3.	*Lack of proper and permanent marking for emergency escape routes and exits. (6, 10, 20, 22, 23, 29)*
G7F4.	*Lack of uninterrupted and adequate lighting system for emergency escape routes and exits. (10, 22, 27, 29)*
G7F5.	*Existing obstacles in front of emergency escape routes and exits making difficult to quit. (6, 10, 22, 29)*
G7F6.	*Failure to display emergency plan, procedures, assembly points and emergency telephone numbers at visible positions. (9, 10, 15, 16, 19, 20, 22, 27, 28, 29)*
G7F7.	*Lack of adequate/proper number and quality of fire detectors. (2, 9, 22, 29)*
G7F8.	*Lack of proper alarm system clearly audible at all points on the site. (10, 16, 27, 29)*
G7F9.	*Lack of regular inspection and maintenance of firefighting equipment, detectors and alarm systems. (6, 9, 29)*
G7F10.	*Failure to conduct fire drill at regular intervals. (6, 9, 10)*

The final list of 12 observable variables in "Hand/power tools, machinery and devices" dimension with respect to their referenced studies are shown in Table 2.27 below.

Table 2.27: The final list of 12 observable variables in “Hand/power tools, machinery and devices” dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G8: HAND/POWER TOOLS, MACHINERY AND DEVICES (2, 3, 4, 5, 6, 8, 9, 10, 12, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 27, 30)	
G8F1.	*Improper use and use for purposes other than it is intended. (15, 19, 21, 22, 23, 27, 28)*
G8F2.	*Use or operate of tools, machines and devices without security protection inserted. (2, 6, 8, 9, 10, 15, 16, 19, 20, 21, 22, 23, 27, 28, 29, 30)*
G8F3.	*Use without making sure of the soundness of the floor and use without fixing. (6, 16, 18, 20, 23, 27, 29)*
G8F4.	*Use or operate in damaged condition. (2, 9, 16, 20, 23, 27, 28, 30)*
G8F5.	*Use or operate by untrained and unauthorized operators. (2, 5, 9, 15, 16, 20, 27, 28, 29)*
G8F6.	*Lack of absence of a trained pointer to guide operator in necessary situations. (5, 9, 15, 16, 20, 22, 27)*
G8F7.	*Lack of daily inspection and maintenance. (2, 6, 9, 11, 12, 15, 16, 17, 19, 20, 21, 22, 27, 28)*
G8F8.	*Lack of safe work instructions. (6, 9, 16, 20, 21, 22, 23, 27, 28)*
G8F9.	*Failure to clean enough. (6, 10, 22)*
G8F10.	*Failure to place barricades and warning signs when not in use. (2, 6, 8, 9, 12, 15, 17, 20, 21, 22, 23, 28)*
G8F11.	*Failure to position in safe distances (E.g.: people, materials, tools, excavation, slope, underground facility, soft ground, obstacles, electricity lines). (10, 20, 21, 25, 27, 28, 29, 30)*
G8F12.	*Failure to use proper personal protective equipment (PPE). (2, 7, 15, 18, 20, 22)*

The final list of 12 observable variables in “Material handling” dimension with respect to their referenced studies are shown in Table 2.28 below.

Table 2.28: The final list of 12 observable variables in “Material handling” dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G9: MATERIAL HANDLING (LOADING, TRANSPORT, UNLOADING, HANDLING AND STORAGE) (2, 6, 9, 10, 11, 13, 14, 15, 16, 19, 20, 22, 24, 25, 27)	
G9F1.	*Lack of proper planning. (2, 6, 9, 22, 23, 29)*
G9F2.	*Transportation by improper vehicles. (11, 14)*
G9F3.	*Failure to comply with safe loading limitations. (9, 16, 18, 20, 28)*
G9F4.	*Loading/unloading/stacking by unsafe vehicles. (2, 6, 11, 14)*
G9F5.	*Failure to design loading places and ramps according to dimensions of the load to be moved. (20, 29)*
G9F6.	*Lack of use of forwarding lines that guide loads. (15, 22)*
G9F7.	*Failure to remove/disposal of hazardous materials and chemicals by specially trained personnel. (6, 9, 15, 16, 20, 27, 29)*
G9F8.	*Storage of hazardous materials and chemicals more than the allowed/exempted amount. (2, 6, 9, 13, 15, 16, 20, 22, 27, 28)*
G9F9.	*Absence of legible warning labels on hazardous materials and chemicals. (6, 9, 15, 16, 20, 22, 23, 27, 28, 30)*
G9F10.	*Absence of Material safety data sheet (MSDS) belonging to hazardous materials and chemicals. (15, 20, 22, 28, 30)*
G9F11.	*Failure to clearly display chemical hazard communication plan. (9, 15, 16, 20, 22, 28)*
G9F12.	*Failure to use proper personal protective equipment (PPE). (11, 16, 18, 22)*

The final list of 12 observable variables in “Traffic and transportation control” dimension with respect to their referenced studies are shown in Table 2.29 below.

Table 2.29: The final list of 12 observable variables in "Traffic and transportation control" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G10: TRAFFIC AND TRANSPORTATION CONTROL (2, 4, 6, 7, 9, 14, 15, 16, 21, 22, 24, 25, 27, 28, 29, 30, 31)	
G10F1.	*Lack of correct and regular inspection and maintenance of vehicles. (2, 6, 16, 20, 27, 30)*
G10F2.	*Failure to use safety belts. (9, 15, 20, 21, 30)*
G10F3.	*Driving vehicle without license. (2, 9, 16, 20, 27)*
G10F4.	*Driving vehicle without experience. (9, 16, 20, 27)*
G10F5.	*Absence of proper and adequate first aid kit/fire extinguisher tube in vehicles. (9, 27, 30)*
G10F6.	*Unclear routes. (6, 10, 12, 13, 15, 16, 17, 22, 25, 27, 29, 30)*
G10F7.	*Roads with inadequate width. (2, 13, 22, 26, 29, 30)*
G10F8.	*Failure to keep adequate distance between roads (having vehicle traffic) and doors, gates, pedestrian passageways, corridors and stairs. (4, 7, 15, 21, 22, 27, 29, 30, 31)*
G10F9.	*Lack of adequate number of direction and warning signs. (9, 10, 13, 21, 22, 23, 27, 28, 29)*
G10F10.	*Failure to comply with speed limits. (6, 16, 28)*
G10F11.	*Failure to take preventive measures against excavation material spillage and dust. (6, 27, 28)*
G10F12.	*Failure to take preventive measures against the entry of unauthorized people to prohibited areas. (10, 27, 29)*

The final list of 8 observable variables in "First aid" dimension with respect to their referenced studies are shown in Table 2.30 below.

Table 2.30: The final list of 8 observable variables in “First aid” dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G11: FIRST AID (2, 6, 9, 10, 14, 15, 16, 20, 21, 24, 27, 28, 29, 30)	
G11F1.	*Absence of trained first aid staff at site. (6, 14, 15, 21, 27, 28, 29)*
G11F2.	*Failure to display first aid staff and their contact information at visible positions. (6, 15, 20, 29)*
G11F3.	*Lack of adequate number of first aid supplies and equipment. (2, 6, 9, 10, 16, 20, 28, 29)*
G11F4.	*Lack of easy to access first aid supplies and equipment. (6, 14, 15, 20, 29, 30)*
G11F5.	*First aid supplies and equipment are not ready for use. (6, 20, 29, 30)*
G11F6.	*First aid supplies and equipment are not marked appropriately. (20, 29, 30)*
G11F7.	*Lack of adequate number of emergency treatment rooms. (9, 14, 16, 19, 29)*
G11F8.	*Absence of on-site doctor. (6, 29)*

The final list of 12 observable variables in “Excavation works” dimension with respect to their referenced studies are shown in Table 2.31 below.

Table 2.31: The final list of 12 observable variables in "Excavation works" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G12: EXCAVATION WORKS (2, 4, 6, 7, 9, 10, 15, 16, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29)	
G12F1.	*Inspection and control of excavation works by unauthorized people. (6, 15, 16, 19, 21, 22, 27)*
G12F2.	*Failure to locate beforehand underground facilities in excavation areas by using detectors, etc. (E.g.: cable, gas, water, sewer lines). (6, 10, 15, 16, 21, 27)*
G12F3.	*Failure to place proper barriers, railings and warning signs. (2, 19, 27)*
G12F4.	*Performing night work without providing adequate lighting. (26, 29)*
G12F5.	*Use of unsafe entry and exit gates to access working area. (6, 9, 10, 16, 20, 21, 27, 29)*
G12F6.	*Failure to place secured stop blocks preventing the vehicles from falling into excavation area. (6, 10, 16, 21, 25, 27, 31)*
G12F7.	*Placing the materials improperly near to the excavation edges. (6, 10, 15, 16, 20, 22, 25, 27, 31)*
G12F8.	*Failure to support properly and adequately by performing static calculations of the excavation area (with slab, timber, trench boxes, shoring, lining, etc.). (9, 10, 15, 16, 18, 19, 20, 21, 22, 27)*
G12F9.	*Sloping the excavation area with improper angles. (2, 4, 6, 10, 16, 25)*
G12F10.	*Performing excavation works while raining. (20, 25)*
G12F11.	*Entry of unauthorized people to the excavation area. (2, 7, 16, 27)*
G12F12.	*Failure to use proper personal protective equipment (PPE). (7, 18, 22)*

The final list of 11 observable variables in "Concrete and formwork" dimension with respect to their referenced studies are shown in Table 2.32 below.

Table 2.32: The final list of 11 observable variables in "Concrete and formwork" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G13: CONCRETE AND FORMWORK (2, 6, 8, 9, 15, 18, 19, 20, 21, 22, 23, 24, 27, 29)	
G13F1.	*Failure to perform form works under the supervision of a competent person. (9, 29)*
G13F2.	*Improper design and installation of form panels, supports and struts with respect to the loads on it. (2, 9, 19, 29)*
G13F3.	*Use of weak and deformed forms. (2, 9, 19, 29)*
G13F4.	*Use of ungrounded electrical vibrator. (9, 27)*
G13F5.	*Exposure of reinforcing bars. (15)*
G13F6.	*Failure to position the concrete pump properly to the ground that concrete will be poured. (29)*
G13F7.	*Failure to fix the concrete pump's supporting foots to the ground. (2, 29)*
G13F8.	*Failure to take account of surrounding facilities while opening and closing pump handles. (29)*
G13F9.	*Operating the pump under energy transmission lines without taking precautions. (29)*
G13F10.	*Performing work directly below the concrete pouring area. (29)*
G13F11.	*Failure to use proper personal protective equipment (PPE). (2, 15, 18, 22, 27, 29)*

The final list of 10 observable variables in "Welding works" dimension with respect to their referenced studies are shown in Table 2.33 below.

Table 2.33: The final list of 10 observable variables in “Welding works” dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G14: WELDING WORKS (2, 6, 8, 9, 10, 15, 18, 20, 22, 24)	
G14F1.	*Lack of daily control and maintenance of the welding equipment. (6, 9, 27)*
G14F2.	*Inadequate ventilation in narrow and confined areas. (9, 10, 27, 28, 29, 30)*
G14F3.	*Failure to keep gas cylinders upright and failure to fasten in order not to overturn when shaked. (2, 6, 9, 15, 16, 20, 27)*
G14F4.	*Absence of proper type of fire extinguisher nearby. (6, 9, 15, 20, 22, 27)*
G14F5.	*Failure to put adequate separation distance between fuels and oxygen. (2, 15, 22, 28)*
G14F6.	*Contact oxygen tube with oily hand. (28)*
G14F7.	*Failure to take precautions against electrical and gas leakage. (6, 22, 27)*
G14F8.	*Use of deformed hoses. (6, 15, 22, 27)*
G14F9.	*Welders without license and certificate. (20)*
G14F10.	*Failure to use proper personal protective equipment (PPE). (2, 6, 7, 8, 9, 15, 18, 20, 22)*

The final list of 9 observable variables in “Demolition works” dimension with respect to their referenced studies are shown in Table 2.34 below.

Table 2.34: The final list of 9 observable variables in “Demolition works” dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G15: DEMOLITION WORKS (6, 20, 22, 24, 26, 27, 29)	
G15F1.	*Lack of preparation and planning of actions before the start of demolition works. (20, 22, 23, 29)*
G15F2.	*Failure to enclose the demolition area and failure to place warning signs. (23, 29)*
G15F3.	*Failure to take existing service lines (gas, water, electricity lines, etc.) under control or failure to cut whereas necessary. (20, 29)*
G15F4.	*Performing demolition works under the supervision of an incompetent person. (29)*
G15F5.	*Failure to remove people, vehicles, materials and equipment enough from the demolition area. (29)*
G15F6.	*Failure to take necessary precautions to avoid dust during demolition. (6, 22, 25, 26, 27, 28, 29)*
G15F7.	*Failure to transport materials and ruins in a systematical and secured way. (6, 11, 14, 20, 25, 29)*
G15F8.	*Failure to perform asbestos powder measurement for structures that may contain asbestos. (6, 15, 26, 27, 29)*
G15F9.	*Failure to use proper personal protective equipment (PPE). (13, 15, 16, 18, 19, 22, 27, 29)*

The final list of 10 observable variables in “Workers” dimension with respect to their referenced studies are shown in Table 2.35 below.

Table 2.35: The final list of 10 observable variables in "Workers" dimension with respect to their referenced studies

Latent Dimension / *Observable Variables (Referenced Study#)*	
G16: WORKERS (4, 5, 6, 10, 11, 12, 13, 14, 15, 16, 17, 19, 21, 22, 26, 27, 28, 29, 30)	
G16F1.	*Avoiding the use of personal protective equipment intentionally. (8, 11, 13, 14, 15, 17, 18, 21, 22, 23, 31)*
G16F2.	*Taking the apparent risks. (7, 8, 11, 14, 15, 17, 22, 23, 25, 27, 29)*
G16F3.	*Performing erroneous methods and applications. (7, 11, 15, 17, 22, 23, 25)*
G16F4.	*Working without plan and cautiousness. (11, 14, 15, 22, 23)*
G16F5.	*Lacking safety consciousness. (11, 14, 15, 22, 23)*
G16F6.	*Working without morale. (11, 14, 23)*
G16F7.	*Working without permission. (22, 23, 28)*
G16F8.	*Use of alcohol and drug. (29)*
G16F9.	*The continuous change of workers (Personnel turnover rate is high). (14)*
G16F10.	*Inadequacy of safety trainings. (11, 14, 15, 28, 29)*

The referenced studies for the final list are shown in Table 2.36 below.

Table 2.36: Referenced studies for the final list

Referenced Studies:
1. *Duff, A. R., Robertson, I. T., Phillips, R. A., and Cooper, M. D. (1994). "Improving safety by the modification of behavior." Construction Management and Economics, 12:67-78.*
2. *Jannadi, M. O., and Assaf, S. (1998). "Safety assessment in the built environment of Saudi Arabia." Safety Science, 29: 15-24.*
3. *Kvaerner (1998). "Site safety performance system." A system developed by Kvaerner Construction (Building), United Kingdom.*
4. *Seixas N.S., Sanders J., Sheppard L., and Yost M. (1998). "Exposure assessment for acute injuries on construction sites: Conceptual development and pilot test". Applied Occupational Environment Hygiene. 13(5): 304-312.*
5. *Laitinen H., Marjamaki M., and Paivarinta K. (1999). "The validity of the TR safety observation method on building construction." Accident Analysis and Prevention. 31: 463-472.*
6. *WBTC (2000). "Score card for assessment of site safety performance." Works Bureau Technical Circular No. 26/2000, Hong Kong, China. Available at: http://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/13/1/c-2000-26-0.pdf (Retrieved: 10.04.2015).*
7. *Glendon, A. I., and Litherland, D. K. (2001). "Safety climate factors, group differences and safety behavior in road construction." Safety Science, 39(3): 157-188.*
8. *Workcover (2001). "Safety Meter, Positive Performance Measurement Tool." A Booklet Published by Workcover, New South Wales, Sydney NSW, Australia. Available at: http://nitinnaik.com/pdf/gen_safetymeter_977.pdf (Retrieved: 10.04.2015).*
9. *Jannadi, O. A., and Bu-Khamsin, M. S. (2002). "Safety factors considered by industrial contractors in Saudi Arabia." Building and Environment, 37(5): 539-547.*
10. *Martin, M. (2002). "SABRE, Construction site safety hazard assessment system: A user's guide." 3rd International Conference on Implementation of Safety and Health on Construction Sites: One Country - Two Systems, 8 - 11 May 2002 Hong Kong, China 13 - 17 May 2002 Beijing, China.*
11. *Zeng, S. X., Wang, H. C., and Tam, C. M. (2002). "A survey of construction site safety in China." 3rd International Conference on Implementation of Safety and Health on Construction Sites: One Country - Two Systems, 8 - 11 May 2002 Hong Kong, China 13 - 17 May 2002 Beijing, China.*
12. *Trethewy, R. W. (2003). "Influences on subcontractor OHS management outcomes in construction." Ph.D. Thesis, University of New South Wales, Australia.*

Table 2.36: Referenced studies for the final list (cont.'d)

Referenced Studies:
13. *McEvoy, P. (2004)."Safety performance on 20 construction sites in Dublin." Master's Thesis, Dublin Institute of Technology, Dublin, Ireland.*
14. *Tam, C. M., Zeng, S. X., and Deng Z. M. (2004). "Identifying elements of poor construction safety management in China." Safety Science, 42(7): 569-586.*
15. *Berry, C.K., and Bogner J.R. (2005). "Construction contractor weekly safety inspection report." A report published by Department of Labor, North Carolina, USA. Available at: http://www.nclabor.com/osha/etta/exampleprograms/Jobsite_Safety_Checklist_%28long_ver%29.doc (Retrieved: 10.04.2015).*
16. *Holt, A. S. J. (2006). "Principles of construction safety." Blackwell Science Ltd., Oxford, United Kingdom. Doi: 10.1002/9780470690529.*
17. *Naik, N. (2006). "A Study of performance measurement of safety systems in construction." PhD Thesis, University of New South Wales, Australia.*
18. *Farooqui, R. U., Arif, F., and Rafeeqi, S.F.A. (2008). "Safety performance in construction industry of Pakistan." Proceedings of the 1st International Conference on Construction in Developing Countries: Advancing and Integrating Construction Education, Research and Practice (ICCIDC-1 2008), Karachi, Pakistan, pp. 74-87.*
19. *Metinsoy, T. (2010). "A method of evaluation of relationship between the safety management and overall safety performance in construction industry." PhD Thesis, Boğaziçi University, Istanbul, Turkey.*
20. *CG Schmidt Inc. (2011). "Weekly Safety and Health Inspection Report." Milwaukee, Wisconsin, USA. Available at: http://www.cgschmidt.com/forms-resources/CGSWeekly Safety & Health Inspection Report.pdf (Retrieved: 10.04.2015).*
21. *MIOSHA (2011). "Construction Safety & Health Management System (Accident Prevention Program)." Michigan Occupational Safety and Health Administration, Department of Licensing and Regulatory Affairs, Lansing, Michigan, USA. Available at: http://www.michigan.gov/documents/cis_wsh_jobsite_safreview_146959_7.doc (Retrieved: 10.04.2015).*
22. *PMCS (2012). "The contractor's handbook: Working successfully at the University of Texas at Austin." University of Texas, Austin, USA.*
23. *COAA (2013). "Best Practice for Behavior Based Safety Construction Owners Association of Alberta (COAA)." Alberta, Canada. Available at: http://www.coaa.ab.ca/safety/home/behaviorbasedsafetybestpractice.aspx (Retrieved: 10.04.2015).*
24. *L&I (2014a). "Construction site hazards to watch out for." A booklet published by Washington State Department of Labor & Industries, Olympia, Washington D.C., USA. Available at: http://www.lni.wa.gov/Safety/Basics/SmallBusiness/Construction/documents/WhatToWatchoutFor.pdf (Retrieved: 10.04.2015).*

Table 2.36: Referenced studies for the final list (cont.'d)

Referenced Studies:
25. *Esmaeili, B., Hallowell, M., and Rajagopalan, B. (2015). "Attribute-based safety risk assessment. II: Predicting safety outcomes using generalized linear models." Journal of Construction Engineering and Management, 10.1061/(ASCE)CO.1943-7862.0000981, 04015022.*
26. *Labor Department (2004). "Guidance notes on health hazards in construction work." Occupational Safety and Health Branch, Labor Department, Hong Kong, China. Available at: http://www.labour.gov.hk/eng/public/oh/OHB82.pdf (Retrieved: 10.04.2015).*
27. *TCH Safety (2006). "Construction site risk assessment tool." Penzance, Cornwall, United Kingdom. Available at: http://www.tchsafety.co.uk/product_pdfs/construction%20site.pdf (Retrieved: 10.04.2015).*
28. *Safety Culture Company (2012). Safety Culture Company (2012). "Construction hazard identification risk assessment audit tool (iAuditor)." A mobile application and checklist developed and published by Safety Culture, Garbutt, Townsville, Queensland, Australia. Available at: http://www.safetyculture.io/iauditor and http://www.auditforms.net/Workplace%20Inspections/workplace%20inspection%20checklist.pdf (Retrieved: 10.04.2015).*
29. *MLSS (2013). "Occupational health and safety regulation for construction works." Ministry of Labor and Social Security, Ankara, Turkey. Available at: http://www.csgb.gov.tr/csgbPortal/ShowProperty/WLP%20Repository/isggm/dosyalar/yapi_isleri_yonetmelik (Retrieved: 10.04.2015).*
30. *L&I (2014b). "Construction safety inspection checklist." A booklet published by Washington State Department of Labor & Industries, Olympia, Washington D.C., USA. Available at: http://www.lni.wa.gov/Safety/Basics/SmallBusiness/Construction/documents/SelfInspectionChecklist.doc (Retrieved: 10.04.2015).*
31. *Li, H., Lu, M., Hsu, S. C., Gray, M., Huang, T. (2015). "Proactive behavior-based safety management for construction safety improvement." Safety Science, ISSN 0925-7535, http://dx.doi.org/10.1016/j.ssci.2015.01.013, 75, 107-117.*

2.6 Chapter summary

This chapter presented the findings of literature review to satisfy objectives of the current thesis proposal. The literature review was carried out through books, journals, conference papers, doctorate theses, master's theses, and the web. More than 250 publications related to safety performance were analyzed and 25 studies directly associated with the current research topic were analyzed in detail. In these referenced studies, dated between 1994 and 2015, a total of 91 categories, 35 headings, 18 divisions, 45 criteria, 102 groups, 810 items, 185 factors, 124 questions, 40 sub-items, 252 considerations, 22 attributes, 20 main factors, and 85 sub-factors (a grand total of 1.829 determinants) were listed as safety performance determinants in construction sites. In this study, abovementioned determinants were screened through expert opinions and least significant findings were removed before the preparation of a questionnaire template.

Firstly, a total of 98 observable variables in 16 latent dimensions affecting safety performance of construction sites were achieved. The list of this observable variables and latent dimensions with respect to their referenced studies was shown. After determining the observable variables and latent dimensions affecting safety performance of construction sites, a questionnaire survey form has been prepared (See Chapter 4) and face-to-face interviews about this template have been made with 15 construction safety professionals, including owners, managers, and engineers-supervisors. Table 2.18 showed the demographics of these interviewees. Taking account of the feedbacks of these construction safety professionals, an additional literature review was made to satisfy the lacking items in the questionnaire template. The findings of this additional literature review were also demonstrated in this chapter. Additional 6 studies directly associated with the current research topic were analyzed in detail. By adding these additional referenced studies, dated between 1994 and 2015, a total of 91 categories, 59 headings, 18 divisions, 45 criteria, 148 groups, 891 items, 226 factors, 368 questions, 40 sub-items, 252 considerations, 22 attributes, 10 behaviours, 20 main factors, and 85 sub-factors (a grand total of 2.279 determinants) were listed as safety performance determinants in construction sites in Table 2.19. Finally, a total of 168 observable variables in 16 latent dimensions affecting safety performance of construction sites were collected together. The final list of this observable variables and latent dimensions of safety performance with respect to their referenced studies were shown in Tables 2.20 to 2.36.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter will give a brief description of a research design and explain research framework and processes of this study. As the research methodology, an exploratory sequential design method (a sequential mixed method in research design) that includes both qualitative and quantitative research methodologies will be implemented. The implemented research methodology and research processes that are formulated to achieve the nine (9) objectives will be explained in detail.

3.2 Research design

Creswell (2009), defined research design as "the plan or proposal to conduct research". It is affected by the worldview assumptions the researcher brings to the study; procedures for inquiry; and specific methods of data collection, analysis, and interpretation. The selection of a research design is also based on the nature of the research problem or issue being addressed, the researcher's personal experiences, and the audiences for the study (Creswell 2009).

Generally, three types of research design have been utilized in the literature as "qualitative, quantitative, and mixed". Qualitative research is "a means for exploring and understanding the meaning individuals or groups ascribe to a social or human problem". Quantitative research is "a means for testing objective theories by examining the relationship among variables". Mixed methods research is "an approach to inquiry that combines or associate both qualitative and quantitative forms" (Creswell 2009).

According to Hung (2012), qualitative and quantitative research design should be viewed as two ends of a continuum, with mixed methods placed in the middle of the continuum, rather than viewing them as polar opposites.

A framework adopted from Creswell (2009), showing how a research design is formulated was depicted in Figure 3.1.

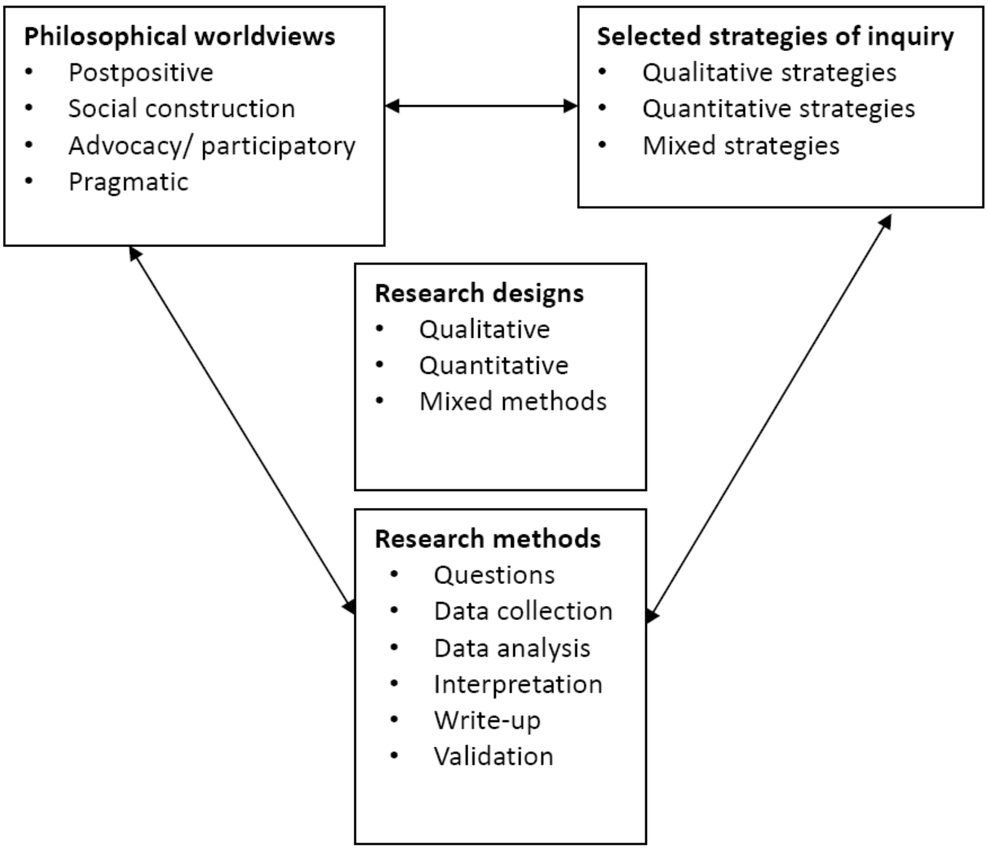


Figure 3.1: Intersected formulating process of research design (Adopted from Creswell 2009)

A research design is the resultant decision of three intersecting elements: 1) the philosophical worldview assumptions; 2) the strategy of inquiry; and 3) the methods or procedures of research that operationalize the approach (Creswell 2009).

3.2.1 Philosophical worldviews

Worldview means "a basic set of beliefs that guide action" (Guba 1990). It is a general orientation about the world and the nature of research that a researcher holds. The worldview of the researcher underpins the decision to choose a qualitative, quantitative, or mixed methods approach.

Post positivists hold a deterministic and reductionistic philosophy (Creswell 2009). They argue that knowledge can be reduced into discrete variables for hypothesis testing. They usually begin their research with a theory and then test the theory with empirical data to support or refute the theory.

Social constructivists assume that individuals seek understanding of the world in which they live and work (Creswell 2009). Constructivists address the processes of interaction between individuals and adopt qualitative research to generate or inductively develop a theory.

Advocacy and participatory worldviews focus on marginalized individuals in the society or issues of social justice that need to be addressed. The research often contains an action agenda that may change the lives of the participants.

Pragmatists are concerned with applications, what works, and solutions to problems (Creswell 2009). Instead of focusing on methods, researchers emphasize the research problem and use all available approaches to understand the problem. Pragmatism is a philosophical underpinning for mixed methods studies (Hung 2012).

3.2.2 Strategies of inquiry

Strategies of inquiry, or research methodologies, are types of qualitative, quantitative, and mixed methods designs or models that provide specific direction for procedures in a research design (Creswell 2009).

Common types of qualitative strategy include ethnography, grounded theory and case studies. Survey research is a common type of quantitative strategy which can be cross-sectional or longitudinal. Survey research uses questionnaires for data collection with the intent of generalizing from a sample to a population (Creswell 2009).

Mixed methods can correct biases inherent in any single method by the biases of other methods. Data can be triangulated and integrated to achieve convergence across qualitative and quantitative methods. Quantitative and qualitative results can support one another to improve validity of the findings (Creswell 2009).

The three main types of mixed methods are the sequential, concurrent, and transformative methods. Sequential mixed methods involve procedures of qualitative methods to quantitative ones in sequence, and vice versa. Concurrent mixed methods involve collecting both forms of qualitative and quantitative data simultaneously, and then integrating the information in the interpretation of the overall results. Transformative mixed methods involve using a theoretical lens as an overarching perspective within a design that contains both qualitative and quantitative data (Creswell 2009).

According to Creswell and Clark (2011), sequential mixed method varies into two types: The explanatory sequential design and the exploratory sequential design. The explanatory sequential design (also referred to as the explanatory design) occurs in two distinct interactive phases (see Figure 3.2). This design starts with the collection and analysis of quantitative data, which has the priority for addressing the study’s questions. This first phase is followed by the subsequent collection and analysis of qualitative data. The second, qualitative phase of the study is designed so that it follows from the results of the first, quantitative phase. The researcher interprets how the qualitative results help to explain the initial quantitative results. For example, the researcher collects and analyzes quantitative data to identify significant predictors of adolescent tobacco use. Finding a surprising association between participation in extracurricular activities and tobacco use, the researcher conducts qualitative interviews with adolescents who are actively involved in extracurricular activities to attempt to explain the unexpected result (Creswell and Clark 2011).

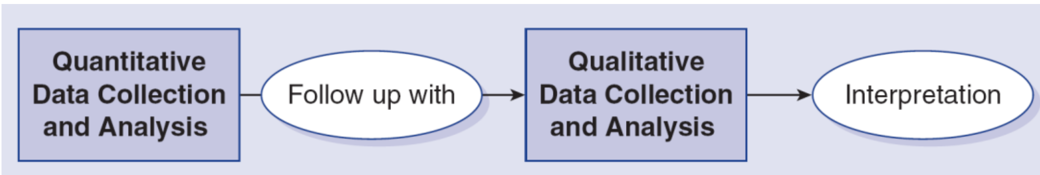


Figure 3.2: Flowchart of explanatory sequential design (Source: Creswell and Clark 2011)

As shown in Figure 3.3, the exploratory sequential design (also referred to as the exploratory design) also uses sequential timing. In contrast to the explanatory design, the exploratory design begins with and prioritizes the collection and analysis of qualitative data in the first phase. Building from the exploratory results, the researcher conducts a second, quantitative phase to test or generalize the initial findings. The researcher then interprets how the quantitative results build on the initial qualitative results. For example, the researcher collects qualitative stories about adolescents’ attempts to quit smoking and analyzes the stories to identify the conditions, contexts, strategies, and consequences of adolescent quit attempts. Considering the resulting categories as variables, the researcher develops a quantitative instrument and uses it to assess the overall prevalence of these variables for a large number of adolescent smokers (Creswell and Clark 2011).

Figure 3.3: Flowchart of exploratory sequential design (Source: Creswell and Clark 2011)

As was depicted in Figure 3.3, the exploratory design is also a two-phase sequential design that can be recognized because the researcher starts by qualitatively exploring a topic before building to a second, quantitative phase. This emphasis on exploration is reflected in the design name. In many applications of this iterative design, the researcher develops an instrument as an intermediate step between the phases that builds on the qualitative results and is used in the subsequent quantitative data collection. For that reason, this design has been referred to as the instrument development design (Creswell et al. 2004) and the quantitative follow-up design (Morgan 1997).

3.2.3 Research methods

Research methods include data collection, analysis, and interpretation of the findings. Qualitative methods tend to be emergent. Such methods ask open-ended questions, use interview data, observation data, document data, and so on, involve text and image analysis, and end up in themes or patterns interpretation. Quantitative methods tend to be predetermined. Such methods ask instrument-based questions, use performance data, attitude data, and so on, and perform statistical analysis and interpretation. Mixed methods use both predetermined and emergent methods. They ask both open-ended and close-ended questions, collect multiple forms of data, and perform statistical analysis, text analysis and cross-interpretation (Creswell 2009).

Recalling the research design framework, the worldviews, the strategies, and the methods all contribute to a research design that tends to be quantitative, qualitative, or mixed. A post positivist tends to adopt the quantitative strategies of inquiry, collect quantitative data, and perform statistical analysis. A constructivist tends to adopt the qualitative strategies of inquiry, collect qualitative data, and perform textual analysis. A pragmatist tends to adopt a mixed methods approach, making use of both quantitative and qualitative data (Hung 2012).

3.3 Research framework of the study

Pragmatism is the underpinning worldview of this study. Pragmatism provides the philosophical foundation to adopt mixed methods as strategy of inquiry (Morgan 2007). Mixed methods research design was encouraged in construction research because it enhances both the validity and the reliability of the study (Abowitz and Toole 2010).

In this study, an exploratory sequential design method, a sequential mixed method in research design, was implemented, starting with qualitative data collection and analysis phase followed by quantitative data collection and analysis phase, built on former phase.

After a thorough literature review on the determinants of safety performance of construction sites, qualitative and quantitative research methods were employed sequentially to achieve the nine (9) research objectives: 1) to identify the observable variables of safety performance of construction sites, 2) to identify the latent dimensions affecting safety performance, 3) to study the relationships between determinants (observable variables and latent dimensions) of safety performance of construction sites, 4) to develop and validate a multidimensional safety performance model, 5) to develop the formulation of the safety performance index of construction sites, 6) to conduct case studies in international construction sites and perform assessment of their safety performance indices and benchmark the results, 7) to develop a short (simple) model as an alternative to the full (proposed) model to assess safety performance ensuring simplicity, fastness and reasonable accuracy, 8) to propose a safety performance index assessment software tool for construction sites by developing a Site Safety Performance (SSP) software and an application for mobile devices based on the empirically validated theoretical model, 9) to discuss and point out top 30 of the observed variables most affecting the “safety performance of construction sites” and provide recommendations to construction safety professionals.

After making a thorough literature review, interviews were conducted with construction safety professionals to identify the determinants (observable variables (Objective 1) and the latent dimensions (Objective 2)) of safety performance of construction sites. According to the findings of interviews, an additional literature review was conducted and the determinants of safety performance were determined (Objectives 1, 2). A questionnaire survey was administered to construction safety professionals to study the relationships between determinants (observable variables and latent dimensions) of safety performance of construction sites (Objectives 1, 2, 3). In the questionnaire survey, data was collected from respondents by linguistic terms as “low, medium, high” for observable variables affecting "Safety Performance of Construction Sites”. A decision table was formed to demonstrate the variable’s effect on "Safety Performance of Construction Sites", by establishing the “Mamdani-style if-and-then fuzzy rules” for all of the 168 observable variables according to the face-to-face interviews made with 15 construction safety professionals having considerable experience at construction sites (Objectives 3, 4). The full list of research processes of this study with the objectives they achieved is shown in Table 3.1.

Table 3.1: Research processes of this study with the objectives they achieved

Research processes and objectives
a) Literature review (Objective 1, 2),
b) Interviews with construction safety professionals (Objective 1, 2),
c) Additional literature review according to the findings of interviews (Objective 1, 2),
d) Administration of questionnaire (Objective 1, 2, 3),
e) Preparations for the data analysis by fuzzy technique (Objective 3, 4),
f) Proposal of a safety performance model in construction sites and determination of hypotheses based on this model (Objective 3, 4),
g) Data analysis by descriptive statistics (Objective 3, 4),
h) Model development and validation by Structural equation modeling (SEM) (Objective 3, 4),
i) Development of safety performance index formulae (Objective 3, 4, 5),
j) Conducting case studies in international construction sites (Objective 6),
k) Development of a short (simple) model as an alternative to the full model (Objective 7),
l) Development of a safety performance index assessment software tool for construction sites (Objective 8),
m) Discussion of results and recommendations to construction safety professionals (Objective 9).

3.4 Research processes of this study with the achieved objectives

3.4.1 Literature review

The literature review was carried out through books, journals, conference papers, doctorate theses, master’s theses, and the web. More than 250 publications related to safety performance have been analyzed and 25 studies were deeply analyzed directly associated with the current research topic, dated between 1994 and 2015. According to the preliminary findings of the referenced studies, dated between 1994 and 2015, a total of 91 categories, 35 headings, 18 divisions, 45 criteria, 102 groups, 810 items, 185 factors, 124 questions, 40 sub-items, 252 considerations, 22 attributes, 20 main factors, and 85 sub-factors (a grand total of 1.829 determinants) were found as safety performance determinants in construction sites. In this study, abovementioned determinants were screened through expert opinions and least significant findings were removed. A total of 98 observable variables in 16 latent dimensions affecting safety performance of construction sites were collected together.

3.4.2 Interviews with construction safety professionals

After determining the observable variables and latent dimensions affecting safety performance of construction sites, a preliminary questionnaire form was prepared as in Appendix A and face-to-face interviews about this template have been made with 15 construction safety professionals, including owners, managers, engineers-supervisors. Table 2.18 showed the demographics of these interviewees.

3.4.3 Additional literature review according to the findings of interviews

Taking account of the feedbacks of these construction safety professionals, Additional 6 studies directly associated with the current research topic were analyzed in detail, dated between 1994 and 2015, a total of 91 categories, 59 headings, 18 divisions, 45 criteria, 148 groups, 891 items, 226 factors, 368 questions, 40 sub-items, 252 considerations, 22 attributes, 10 behaviours, 20 main factors, and 85 sub-factors (a grand total of 2.279 determinants) were listed as safety performance determinants in construction sites in Table 2.19. Finally, a total of 168 observable variables in 16 latent dimensions affecting safety performance of construction sites were collected together.

3.4.4 Administration of a questionnaire

After making the face-to-face interviews about the preliminary questionnaire form with 15 construction safety professionals, conducting additional literature review, and figuring out a total of 168 observable variables in 16 latent dimensions affecting safety performance of construction sites, a final questionnaire form was developed as in Appendix B. This questionnaire form has been published on a web site (www.surveymonkey.com) in 2 different languages (Turkish and English). This form consisted of 3 main sections including information about survey, information about respondents and determination of relative importance effects (weights) of 168 observable variables in 16 latent dimensions on "Safety Performance of Construction Sites" (According to the variables' "Probability of an incident" and "Impact of an incident" (In a 3-point linguistic Likert-scale as "low, medium, high")).

As a result of the questionnaire survey, 1029 respondents achieved to submit the questionnaire form. Out of 1029, 180 respondents fully completed the whole survey.

3.4.5 Preparations for the data analysis by fuzzy technique

As explained previously, in the questionnaire survey, data was collected from respondents by linguistic terms as "low, medium, high" for observable variables affecting "Safety Performance of Construction Sites". (1) the formation of Mamdani-style if-and-then fuzzy rules according to the expert judgement (face-to-face interviews made with 15 construction safety professionals having considerable experience at construction sites), and (2) the adopted methodology in the utilization of fuzzy technique (selection of linguistic terms, fuzzy membership functions, and defuzzification procedure) was explained. In this context, the form of Mamdani-style fuzzy rules (Mamdani and Assilian 1975) was implemented due to the advantages of the Mamdani's approach, being the most popular in the literature, also being intuitive, having widespread acceptance, and well-suited to human input (Kaur and Kaur 2012). According to the selected triangular and trapezoidal fuzzy membership functions, the linguistic terms were defuzzified into concrete numbers as similar to Chen (1997) and Yener (2007).

3.4.6 Proposal of a safety performance model in construction sites and determination of hypotheses based on this model

Proposal of a safety performance model and the determination of the hypotheses based on this model was presented. As previously mentioned, a total of 98 observable variables in 16 latent dimensions affecting safety performance of construction sites were achieved through literature review and expert opinions. After determining the observable variables and latent dimensions affecting safety performance of construction sites, a preliminary safety performance model was prepared and the hypotheses based on this model were determined. After making the face-to-face interviews about the preliminary questionnaire form with 15 construction safety professionals, conducting additional literature review, and figuring out a total of 168 observable variables in 16 latent dimensions affecting safety performance of construction sites, a final safety performance model have been formed and the research hypotheses were determined accordingly.

3.4.7 Data analysis by descriptive statistics

In-depth statistical analysis of the acquired data were explained. IBM SPSS Statistics computer program was used for the analyses. In search of the characteristics of the respondents, descriptive statistical analyses were performed according to the information obtained from the respondents. Accordingly, the mean, standard error, median, mode, standard deviation, sample variance, kurtosis, skewness, range, minimum, and maximum values of the gathered data were calculated by IBM SPSS Statistics can be found in Appendix D. Respondents' working sectors, working parties, positions at their companies, possession of occupational safety expertise certificates, areas of expertise of current companies respondents work for, experience of the respondents in their current companies, and experience of the respondents in the construction industry were presented as important descriptive information of the respondents.

3.4.8 Model development and validation by structural equation modeling (SEM)

The preparation of the SEM analyses, the choice of the type of the input matrix, estimation techniques, analysis approach, selection of goodness of fit indices, data screening (missing values), examination of univariate and multivariate normality, and sample size requirements were explained in a detailed manner. After having described the preparation of the analyses for SEM, the assessment of the measurement model by SEM was presented inclusive of content validity, unidimensionality, convergent validity, goodness of fit, reliability (internal consistency and composite reliability), and discriminant validity testings. Analysis of the measurement model was carried out using factor analysis by first-order and second-order confirmatory factor analysis (CFA) for the assessment of unidimensionality, convergent validity, reliability, and discriminant validity. After achieving the validity of the measurement model, the equations calculated by LISREL corresponding to the measurement model (associations between the latent factors and respective observable variables) and the structural model (associations between first-order and second-order latent factors) were presented in Appendix E and Appendix F. Finally, the assessment of the structural model including the testing of hypothesized second-order factor structural model by structural equation modeling (SEM) as a confirmatory assessment of structural validity, and the testing of the research hypotheses were explained comprehensively. Hypothesis testing results showed that, all of the research hypotheses were supported.

3.4.9 Development of safety performance index formulae

In the development of the safety performance index formulae, the adopted methodology from Yoo and Donthu (2001) and Avcılar (2010) was presented in this part. Accordingly, calculations of the relative weights of the 16 different latent dimensions of “Safety Performance of construction sites” were performed based on the findings of the previous chapters, and formulation of the Safety Performance Index of Construction Sites was explained.

3.4.10 Conducting case studies in international construction sites

Case studies were conducted at 11 international construction sites to assess their safety performance indices. Investigations were made and evaluation forms (including the full list of 168 observable variables in 16 latent dimensions of safety performance of construction sites) were filled (taking into account of a scale between 0 to 100, where 0: Conformity is minimum, 100: Conformity is maximum, NA: If not applicable) at the construction sites by safety engineers of the companies working for the Case study projects. For all of the 11 Case studies; the Site Safety Performance Indices and the safety performance level of each 16 latent dimensions were calculated. The Site Safety Performance Indices of 11 Case studies were benchmarked and results were demonstrated in descending order.

3.4.11 Development of a short (simple) model as an alternative to the full model

A proposal of a short (simple) model (48 observed variables in 16 latent dimensions) as an alternative to the full model (168 observed variables in 16 latent dimensions) was explained. Results of safety performance by the short (simple) model and the full model were compared for Case studies #1 to #11. Deviations of the results of the short model from the results of the full model were calculated. The average deviation of the short model results from full model results was found to be + 3,14%, smaller than 5%, therefore it was found quite reasonable to utilize the proposed short model taking the advantages of its simplicity, fastness and reasonable accuracy.

3.4.12 Development of site safety performance (SSP) software and application for mobile devices on a cross-platform

The development of a Site Safety Performance (SSP) web application software and SSP mobile application for mobile devices on a cross-platform were explained. Brief information about mobile application categories namely native mobile, mobile-web and hybrid mobile applications were presented. Overall comparison between the three possible types of mobile applications was made. After giving basic information about HTML5, CSS3 and JavaScript languages in the coding the mobile application, the most widely used cross-platform Software Development Kits were presented. The development of a Site Safety Performance (SSP) web application software by using the HTML5, CSS3 and JavaScript coding languages was explained and the snapshots of the developed pages of the web application software were demonstrated.

Considering PhoneGap's advantages of being a standards-based, open source development framework, free to download, with community-built development tools and plugins (Karadimce and Bogatinoska 2014) and being the most popularly growing platform (VisionMobile 2013), in this study, PhoneGap was selected to develop a hybrid mobile application. The development procedure of the Site Safety Performance (SSP) application for mobile devices built on the previously developed SSP web application software by PhoneGap were explained. Snapshots of the application and its pages were demonstrated.

3.4.13 Discussion of results and recommendations to construction safety professionals

The findings of the observed variables and latent dimensions affecting safety performance was discussed. 16 latent dimensions affecting safety performance of construction sites were mentioned with respect to their relative weights. In the following parts, each dimension was discussed separately. Relative effects of the observed variables to the Safety Performance of Construction Sites was calculated. In each latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were given. In each latent dimension, top three of the observed variables most affecting the "safety performance of construction sites" were mentioned. Top 30 of the observed variables most affecting the "safety performance of construction sites" were discussed and recommendations to construction safety professionals were provided to improve the safety performance of construction sites. A full list of 168 recommendations were presented in Appendix J.

3.5 Chapter Summary

This chapter made a brief description of a research design and explained research framework and processes of this study. As the research methodology, an exploratory sequential design method (a sequential mixed method in research design) that includes both qualitative and quantitative research methodologies was implemented in this study. The implemented research methodology and thirteen (13) research processes formulated to achieve the nine (9) objectives of this study were explained in detail.

CHAPTER 4

PREPARATION, DEVELOPMENT AND ADMINISTRATION OF A QUESTIONNAIRE SURVEY

4.1 Introduction

This chapter presented the preparation, development and administration of the questionnaire form to construction professionals having considerable experience in construction sites. Firstly, the preliminary questionnaire form was presented. After making the face-to-face interviews about the preliminary questionnaire form with 15 construction safety professionals, additional literature review was conducted and a final questionnaire form was developed. Also, brief information about administration of the final questionnaire was explained. The main sections included in the questionnaire form was mentioned. Information regarding the survey responses were presented.

4.2 Preparation of the preliminary questionnaire form

As previously mentioned, a total of 98 observable variables in 16 latent dimensions affecting safety performance of construction sites were achieved through literature review and expert opinions. After determining the observable variables and latent dimensions affecting safety performance of construction sites, a preliminary questionnaire form was prepared as in Appendix A.

4.3 Development of the final questionnaire form

After making the face-to-face interviews about the preliminary questionnaire form with 15 construction safety professionals, conducting additional literature review, and figuring out a total of 168 observable variables in 16 latent dimensions affecting safety performance of construction sites, a final questionnaire form was developed as in Appendix B.

4.4 Administration of a questionnaire survey to construction professionals having considerable experience in construction sites

In the previous part, a final questionnaire form was developed including a total of 168 observable variables in 16 latent dimensions affecting safety performance of construction sites. This questionnaire form was published on a web site (www.surveymonkey.com) in 8 different versions:

- https://tr.surveymonkey.com/s/SafetyTR2,
- https://tr.surveymonkey.com/s/SafetyTR1,
- https://tr.surveymonkey.com/s/SafetyENG2,
- https://tr.surveymonkey.com/s/SafetyENG1,
- https://tr.surveymonkey.com/s/2MNRHS2,
- https://tr.surveymonkey.com/s/2MF5LRH,
- https://tr.surveymonkey.com/s/3TY7H6T,
- https://tr.surveymonkey.com/s/3T7GGSN,

and in 2 different languages (Turkish and English). This form consisted of 3 main sections including information about survey, information about respondents and determination of relative importance effects (weights) of 168 observable variables in 16 latent dimensions on "Safety Performance of Construction Sites"

(According to the variables' "Probability of an incident" and "Impact of an incident" (In a 3-point linguistic Likert-scale as "low, medium, high")).

As a result of the questionnaire survey, 1029 respondents checked the online questionnaire. However, out of 1029, 180 respondents fully completed the whole survey.

4.5 Chapter summary

This chapter presented the preparation, development and administration of the questionnaire form to construction professionals having considerable experience in construction sites. As previously mentioned, a total of 98 observable variables in 16 latent dimensions affecting safety performance of construction sites were achieved through literature review and expert opinions. After determining the observable variables and latent dimensions affecting safety performance of construction sites, a preliminary questionnaire form was prepared. After making the face-to-face interviews about the preliminary questionnaire form with 15 construction safety professionals, conducting additional literature review, and figuring out a total of 168 observable variables in 16 latent dimensions affecting safety performance of construction sites, a final questionnaire form was developed (See Appendix B). Then, brief information about administration of the final questionnaire form to the construction professionals having considerable experience in construction sites was explained. The 3 main sections included in the question form was mentioned. Information regarding the survey responses were elucidated. As a result of the questionnaire survey, 180 full responses (Out of 1029 responses) were successfully achieved.

CHAPTER 5

THEORETICAL REVISION OF FUZZY SET THEORY, DATA COLLECTION AND PREPARATION FOR ANALYSIS BY FUZZY OPERATIONS

5.1 Introduction

In the previous chapter, as a result of the questionnaire survey, 1029 respondents checked the online questionnaire and out of 1029, 180 respondents fully completed the survey. In the questionnaire survey, data was collected from respondents by linguistic terms as “low, medium, high” for observable variables affecting "Safety Performance of Construction Sites”. In this chapter, theoretical revision of fuzzy set theory, data collection and preparation for analysis by fuzzy operations will be explained in detail.

This chapter will describe the basics of fuzzy set theory, fuzzy inference and fuzzy modeling. This chapter will present a general background of the fuzzy set theory and fuzzy methodologies that were utilized within the current study. After theoretical revision of fuzzy set theory, the formation of Mamdani-style if-and-then fuzzy rules according to the expert judgement and the adopted methodology in the utilization of fuzzy technique (selection of linguistic terms, fuzzy membership functions, and defuzzification procedure) will be explained.

5.2 Fuzzy logic, fuzzy sets and membership functions

The concept of fuzzy logic was first introduced in 1965 by Zadeh in his seminal paper on fuzzy sets (Zadeh 1965). Since then, research on fuzzy set has expanded to cover a wide range of disciplines and applications (Hishammuddin 2008). Fuzzy set theory provides:

- a strong and significant instrument for the measurement of ambiguities, impreciseness, uncertainties, and unreliabilities,
- the opportunity to meaningfully represent concepts expressed in the natural language.

Fuzzy sets can be considered as an extension of classical or 'crisp' set theory. In classical set theory, an element x is either a member or non-member of set A. Thus, the membership $\mu A(x)$ of x into A is given by:

$$\mu_A(x) = \begin{cases} 1, & \text{if } x \in A \\ 0, & \text{if } x \notin A \end{cases}$$

Consider room temperature as an example. One might say that "a temperature less than 10°C is cold". This statement can be represented in the form of classical set as cold = $\{x|x \leq 10\}$ and the membership function characterizing this set is shown in Figure 5.1.

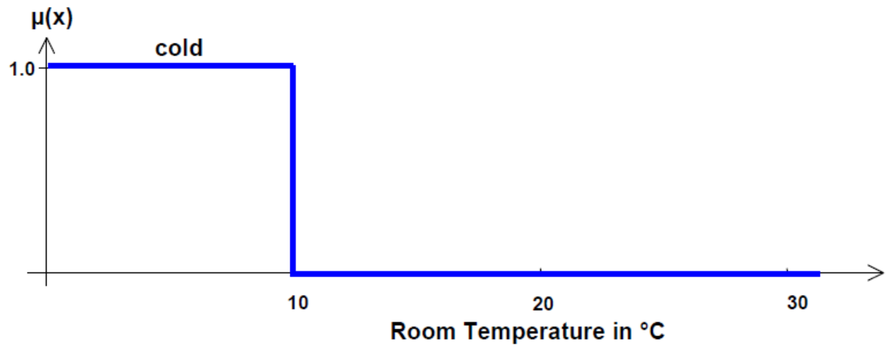


Figure 5.1: Membership function for the set of cold temperatures, defined as cold = $\{x|x \leq 10\}$

In contrast to classical set theory, the fuzzy set methodology introduced the concept of degree to the notion of membership. More formally, a fuzzy set A of a universe of discourse X (the range over which the variable spans) is characterized by a membership function $\mu A(x)$: $X \rightarrow [0, 1]$ which associates with each element x of X a number $\mu A(x)$ in the interval [0, 1], with $\mu A(x)$ representing the grade of membership of x in A. The precise meaning of the membership grade is not rigidly defined, but is supposed to capture the 'compatibility' of an element to the notion of the set.

Returning to the example above, an everyday statement like "a temperature below about 10°C is considered cold" can be represented in the form of the fuzzy set shown in Figure 5.2. In comparison with classical set in which only sharp boundaries are permitted, the concept of membership degree in fuzzy sets allows fuzzy or blurred boundaries to be defined. In Figure 5.2, it can be seen that a temperature of 11°C can also be considered as cold but with a lesser degree of membership than for 10°C (i.e. $\mu_{cold}(x = 11) = 0.85$); whereas in a classical set the degree of membership is zero (i.e. a temperature of 11°C does not belong to the set cold at all). Fuzzy sets provide the tools to represent problems in everyday language, and it is this property that provides a problem solving technique that mimics the characteristics of human reasoning and decision making (Hishammuddin 2008).

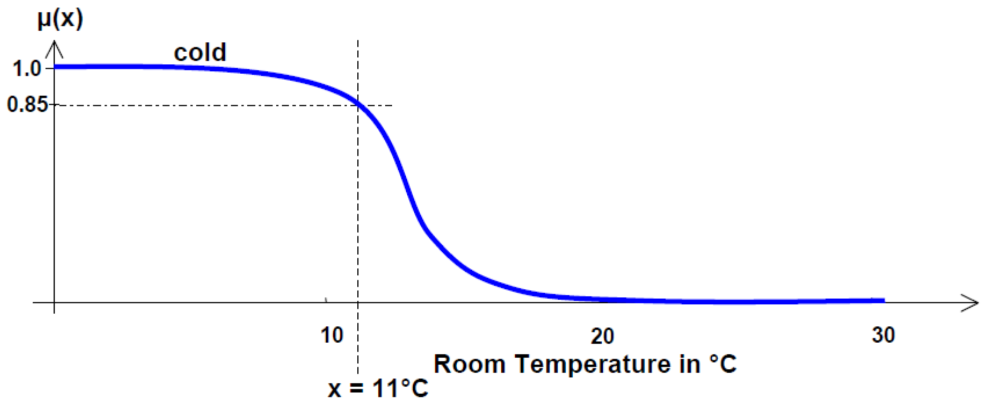


Figure 5.2: Membership function for the fuzzy set cold = {x | x is less than about 10}

5.3 Linguistic variables, values, rules

The term ‘linguistic variable’ was introduced to refer to a variable whose values are in the form of “linguistic expressions” rather than numerical values. In the example shown in Figure 5.2, ‘temperature’ is a linguistic variable with a linguistic value ‘cold’. Other possible linguistic values for the linguistic variable ‘temperature’ could include terms such as ‘moderate’, ‘warm’ and ‘hot’. Each linguistic value is represented by a fuzzy set (membership function) in which the characteristic of each fuzzy set is dependent on the context of the particular problem. Although these linguistic terms are very subjective, they might be interpreted as (for example):

- ‘cold’ to be a temperature below about 10 ℃
- ‘moderate’ to be a temperature around 15 ℃
- ‘warm’ to be a temperature around 20 ℃
- ‘hot’ to be a temperature above about 25 ℃

In a universe of discourse U = [0, 50], these linguistic values would be associated with fuzzy sets whose membership functions are as follows:

$$\mu_{cold}(x) = \begin{cases} 1, & \text{if } x \leq 10 \\ 1-(x-10)/5, & \text{if } 10 < x < 15 \\ 0, & \text{otherwise} \end{cases}$$

$$\mu_{moderate}(x) = \begin{cases} 1-|x-15|/5, & \text{if } 10 < x < 20 \\ 0, & \text{otherwise} \end{cases}$$

$$\mu_{warm}(x) = \begin{cases} 1-|x-20|/5, & \text{if } 15 < x < 25 \\ 0, & \text{otherwise} \end{cases}$$

$$\mu_{hot}(x) = \begin{cases} 1, & \text{if } x \geq 25 \\ 1-(x-30)/5, & \text{if } 20 < x < 25 \\ 0, & \text{otherwise} \end{cases}$$

Graphical representations of these fuzzy sets are shown in Figure 5.3. Over the universe of discourse, the temperature T is partitioned into four fuzzy sets — cold, moderate, warm and hot. These fuzzy sets are partially overlapping. Hence, it can be seen that the room temperature of 18°C has partial membership in both the fuzzy set moderate and the fuzzy set warm, where;

$$\begin{aligned} \mu_{moderate}(x=18) &= 0.25, \quad \text{and} \\ \mu_{warm}(x=18) &= 0.75 \end{aligned}$$

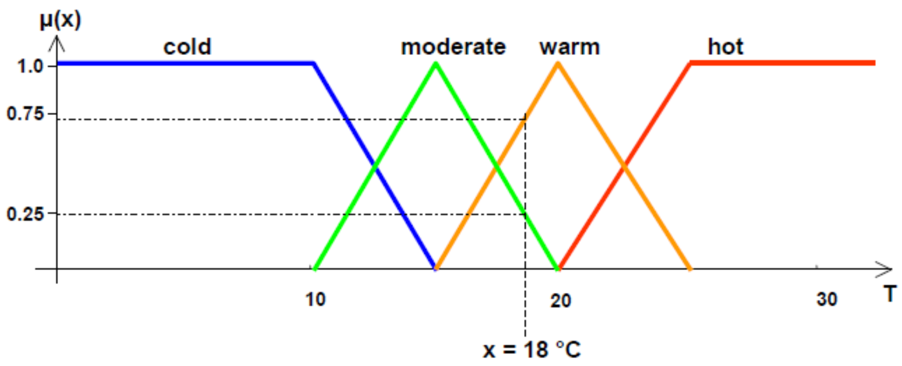
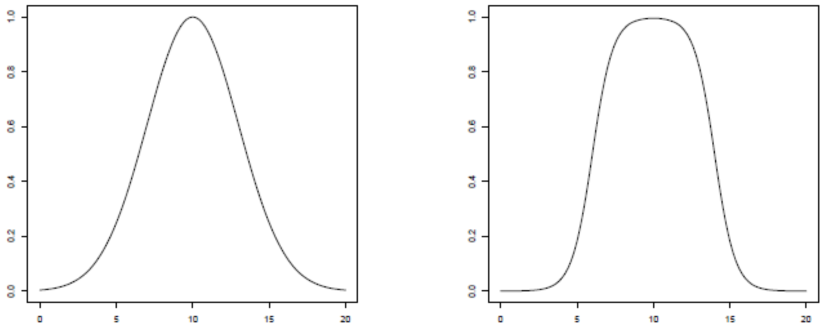


Figure 5.3: Membership functions for the linguistic variable 'temperature'

In this example, triangular and trapezoidal shape membership functions are defined. In practice, any kind of membership functions that are suitable for the problem in hand can be defined and used. Some common functions are depicted in Figure 5.4.



(a) Gaussian (b) Sigmoid

Figure 5.4: Some common membership functions

In order to perform fuzzy inference, rules, which connect input variables to output variables in 'IF ... and… THEN ...' form, are used to describe the desired system response in terms of linguistic variables (words) rather than mathematical formulae. The 'IF' part of the rule is referred to as the 'antecedent', the 'THEN' part is referred to as the 'consequent'. The number of rules depends on the number of inputs and outputs, and the desired behavior of the system. Once the rules have been established, such a system can be viewed as a non-linear mapping from inputs to outputs.

Based on this general form of fuzzy rules, several alternative ways of defining fuzzy rules have been used for fuzzy knowledge engineering (Kasabov (1998). These several types of fuzzy rules are:

- Mamdani-style fuzzy rules.
- Fuzzy rules with confidence degrees.
- Takagi-Sugeno's fuzzy rules.
- Gradual fuzzy rules.
- Generalized production rules with degrees of importance, noise tolerance, and sensitivity factors.

- Generalized production rules with variables.
- Recurrent fuzzy rules.

In this study, the form of Mamdani-style fuzzy rules (Mamdani and Assilian 1975) was implemented due to the advantages of the Mamdani's approach, being the most popular in the literature, also being intuitive, having widespread acceptance, and well-suited to human input (Kaur and Kaur 2012).

In Mamdani's approach, rules are of the form:

$$Ri : \text{if } (x_1 \text{ is } A_{i1}) \text{ and ... and } (x_r \text{ is } A_{ir}) \text{ then } (y \text{ is } C_i) \text{ for } i = 1, 2, ..., L$$

Where L is the number of rules, x_j (j =1, 2, 3, ..., r) are input variables, y is the output variable, and A_{ij} and C_i are fuzzy sets that are characterized by membership functions $A_{ij}(x_j)$ and $C_i(y)$, respectively. In the fuzzy logic process, each rule is evaluated in order to determine the degree of fulfillment of the rule (Hishammuddin 2008).

5.4 Fuzzy operators

The main fuzzy operations defined by Zadeh (1965) are as follows:

Let A and B be two fuzzy sets with membership functions $\mu A(x)$ and $\mu B(x)$ respectively. The intersection operation (which corresponds to the logical 'AND') is defined as:

$$\mu A \cap B(x) = \min [\mu A(x), \mu B(x)] \qquad \text{(Equation 5.1)}$$

and the union operation (which corresponds to the logical 'OR') is defined as:

$$\mu A \cup B(x) = \max [\mu A(x), \mu B(x)] \qquad \text{(Equation 5.2)}$$

In addition, the complement operator (which corresponds to the logical 'NOT') is defined as:

$$\mu_{\bar{A}}(x) = 1 - \mu A(x) \qquad \text{(Equation 5.3)}$$

A graphical representation of these operations is shown in Figure 5.5 (Hishammuddin 2008).

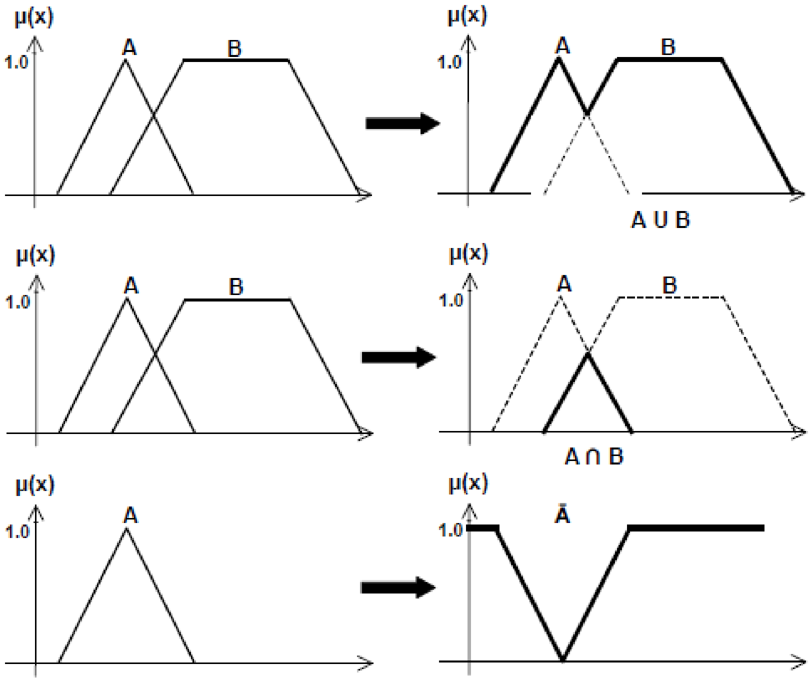


Figure 5.5: Fuzzy sets operations (Negnevitsky 2002)

5.5 Defuzzification methods

The final output is one or more arbitrarily complex fuzzy sets which (usually) need to be defuzzified. Defuzzification is a mathematical process used to extract crisp output from fuzzy output set(s). Various types of defuzzification have been suggested in literature (Cox and O'Hagen 1998). The properties of the specific application being developed will determine which defuzzification method can be utilized. However, there is no systematic procedure to choose which method is the most suitable for any given application (Hishammuddin 2008). In the following sections, the most often used defuzzification methods are described.

5.5.1 The mean of maxima (MOM) method

The Mean of Maxima method returns the average of the base-variable values at which their membership values reach the maximum. The formula is given by:

$$x^* = \sum_{j=1}^{k} \frac{x_j}{k}$$

Where k is the number of discrete elements of the output fuzzy set that reach the maximum memberships. The graphical illustration of the method is shown in Figure 5.6 (Hishammuddin 2008).

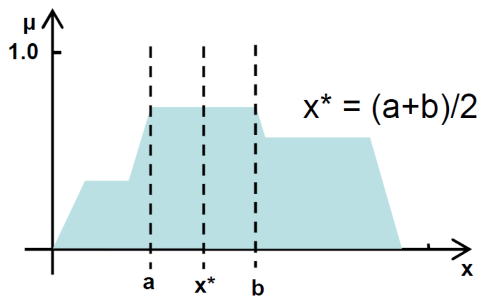


Figure 5.6: The Mean of Maxima (MOM) method of defuzzification

5.5.2 The smallest of maxima (SOM) and the largest of maxima (LOM) methods

The Smallest of Maxima method returns the smallest value of x that belongs to [a, b] at which their membership values reach the maximum. Meanwhile, The Largest of Maxima method returns the largest value of x that belongs to [a, b].

A graphical illustration of these methods is shown in Figure 5.7 (Hishammuddin 2008).

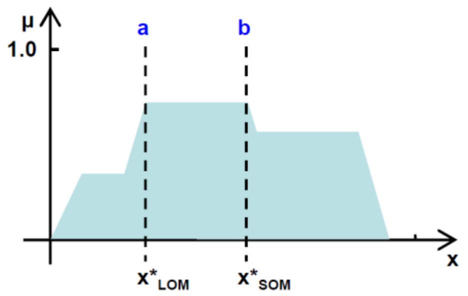


Figure 5.7: The Smallest of Maxima (SOM) and The Largest of Maxima (LOM) methods of defuzzification

5.5.3 The bisector of area (BOA) method

The Bisector of Area (BOA) Method returns the vertical line that partitions the region into two sub-regions of equal area. This method satisfies;

$$\int_{\alpha}^{x*} \mu_A(x)dx = \int_{x*}^{\beta} \mu_A(x)dx$$

Where,

$$\alpha = min\{x|x \in X\} \text{ and } \beta = max\{x|x \in X\}$$

A graphical illustration of this method is shown in Figure 5.8 (Hishammuddin 2008).

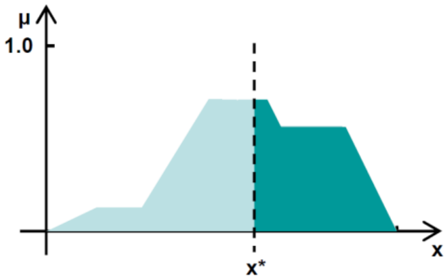


Figure 5.8: The Bisector of Area (BOA) method of defuzzification

5.5.4 Center of gravity (COG) method

Probably the common form of defuzzification is termed the ‘center of gravity’ method, as it is based upon the notion of finding the centroid of a planar figure. This method can be expressed mathematically as follows:

$$x^* = \frac{\int_a^b \mu(x) \cdot x dx}{\int_a^b \mu(x) dx}$$

Theoretically, the output is calculated over a continuum of points in the aggregate membership function. In practice, an approximate value can be derived by calculating it over a sample of points. The formula is given by:

$$x^* = \frac{\sum_a^b \mu(x) \cdot x}{\sum_a^b \mu(x)}$$

Figure 5.9 shows a graphical illustration of the method of finding the point representing the center of gravity in the interval [a, b] for the output fuzzy set (Hishammuddin 2008).

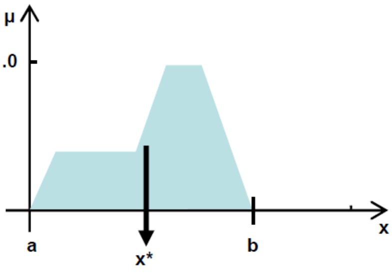


Figure 5.9: The Center of Gravity (COG) method of defuzzification

5.6 Overview of fuzzy systems

Figure 5.10 shows the five interconnected components of a fuzzy system. The fuzzification component computes the membership grade for each crisp input variable based on the membership functions defined. The inference engine then conducts the fuzzy reasoning process by applying the appropriate fuzzy operators in order to obtain the fuzzy set to be accumulated in the output variable. The defuzzifier transforms the output fuzzy set to a crisp output by applying a specific defuzzification method.

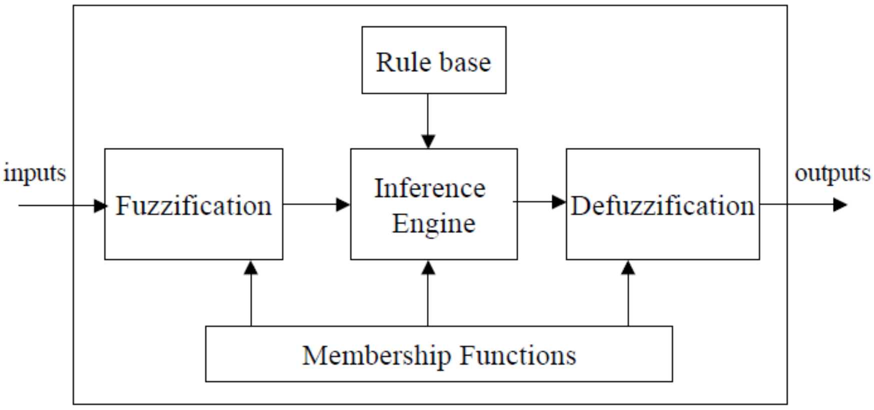


Figure 5.10: Components of fuzzy system

Briefly, the main steps in fuzzy system design are as follows:

- Analyze and understand the problem in consideration.
- Determine the linguistic variables (the inputs and outputs). For each linguistic variable, identify the linguistic values and define the fuzzy sets (membership functions).
- Identify and define the fuzzy rule set.
- Choose the appropriate methods for fuzzification, fuzzy inference and defuzzification.
- Evaluate the system.

If necessary, this sequence of steps is then repeated an arbitrary number of times while fine tuning the fuzzy system by modifying the fuzzy input/output sets and/or fuzzy rules.

In reality, modeling a fuzzy system is a difficult task. Finding a sufficiently good system can be viewed as a search problem in high-dimensional space, in which each point represents a rule set, the membership functions, and the evaluation function is some measure of the corresponding system behavior. This is due to the fact that the performance of a fuzzy system is highly dependent on how the system developer defines the linguistic variables, the membership functions, fuzzy rules set and so on. No formal methods exist to determine the appropriate fuzzy model in a given context. The term 'fuzzy model' is used to mean the combination of selected linguistic variables (input and output variables), membership functions for each linguistic variable and a rule set. Most of the time, the system is either built based on expert knowledge or by systematically training the system using the available data. There are many alternative ways in which this general fuzzy methodology can be implemented in any given problem. In this thesis, the standard Mamdani style fuzzy inference was used with standard Zadeh operators.

Consider a simple example, in order to understand how Mamdani style fuzzy inference works. This example is for a fuzzy system with two input variables and one output variable. The purpose of this example is to illustrate how the final crisp output is obtained for the particular input values (Hishammuddin 2008).

Step 1 -Determining linguistic variables and fuzzy sets. Let the two inputs be represented as linguistic variables A and B; and the output as linguistic variable C. A_1, A_2 and A_3 are linguistic values for A; B1, B2 and B3 are linguistic values for B; C_1, C_2 and C_3 are linguistic values for C with membership functions as shown in the graphical representations given in Figure 5.11.

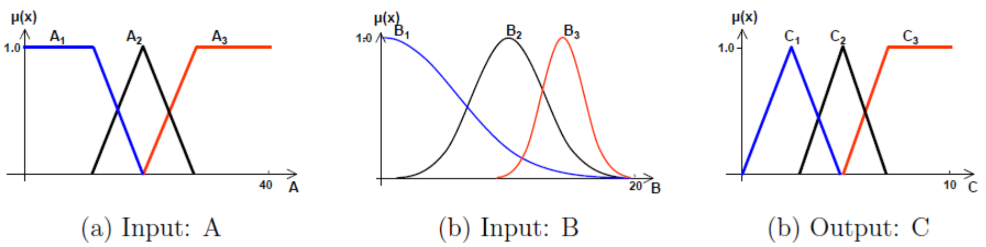


Figure 5.11: Characteristic of linguistic variables

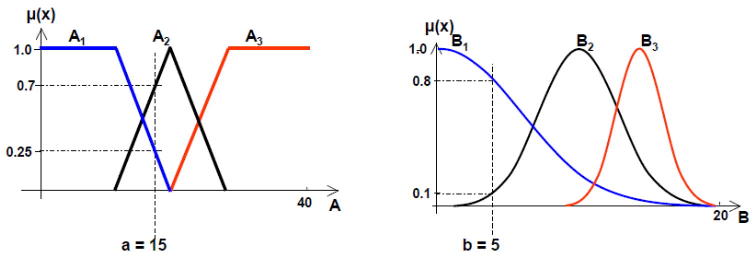
Rules are defined as follows:

Rule 1: IF (a is A_1) AND (b is B_1) THEN (c is C_1)

Rule 2: IF (a is A_2) OR (b is B_2) THEN (c is C_2)

Rule 3: IF (a is A_3) AND (b is B_3) THEN (c is C_3)

Step 2 -Fuzzification. The fuzzified values for input values a = 15 and b = 5 are shown in Figure 5.12.



(a) Input: A (b) Input: B

Figure 5.12: The fuzzified value for both input linguistic variables

Step 3 -Fuzzy Inferencing (Evaluate Rules). The firing level for each rule is determined using the min-max operator shown in Equations 4.1 and 4.2. If the AND operator appears in the antecedents part, the minimum fuzzified value will be selected. On the other hand, if the OR operator appears, the maximum fuzzified value will be selected. Figure 5.13 shows the process graphically. It can be seen that Rule 3 is not activated because both input values (i.e. a = 15 and b = 5) have zero membership degree for the linguistic values A3 and B3 respectively.

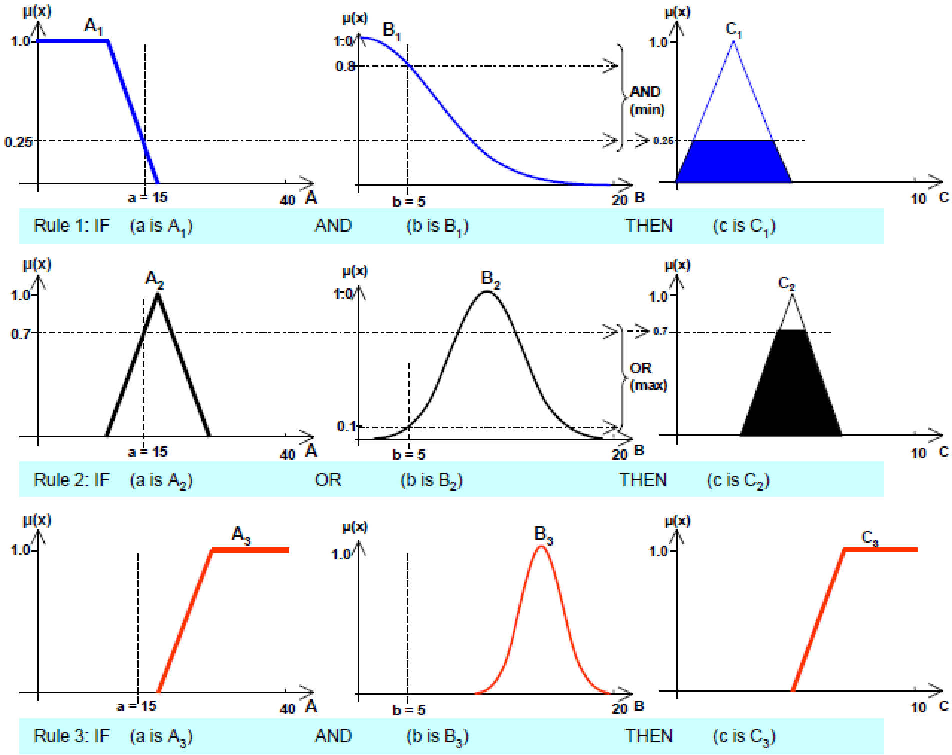


Figure 5.13: Evaluation of rules fulfillment (firing levels)

Step 4 -Rules Output Aggregation. Having evaluated all the rules, the final shape of the output is determined by combining all of the activated rule consequents. The aggregation result is shown in Figure 4.16.

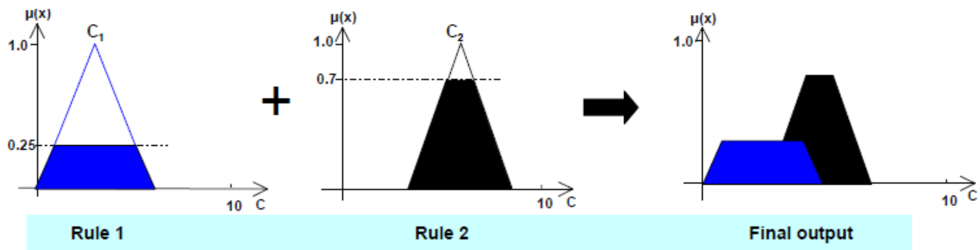


Figure 5.14: Aggregation of rules

Step 5 -Defuzzification. Center of Gravity method of defuzzification is used to defuzzify the output fuzzy set. Figure 5.15 shows the calculated 'center of gravity' of the final output fuzzy set for this simple example problem.

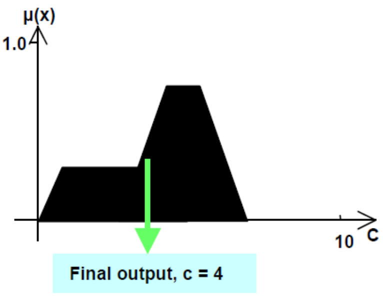


Figure 5.15: Defuzzification of final shape

Even when created with expert knowledge, the system invariably needs to be fine-tuned in order to obtain a satisfactory system performance (where 'satisfactory' may be defined in terms of how good is the fuzzy system is compared to the equivalent manual system; or perhaps in terms of whether the system behaves as previously specified; etc.) (Hishammuddin 2008).

In spite of the fact that sophisticated search techniques are often utilized in fuzzy tuning, it was outside the scope of this thesis to perform any extensive application of such methods.

5.7 Defuzzification of trapezoidal fuzzy numbers

According to Kaufmann and Gupta (1988), a fuzzy number M of the universe of discourse U may be characterized by a trapezoidal distribution parameterized by (a, b, c, d) was shown in Figure 5.16.

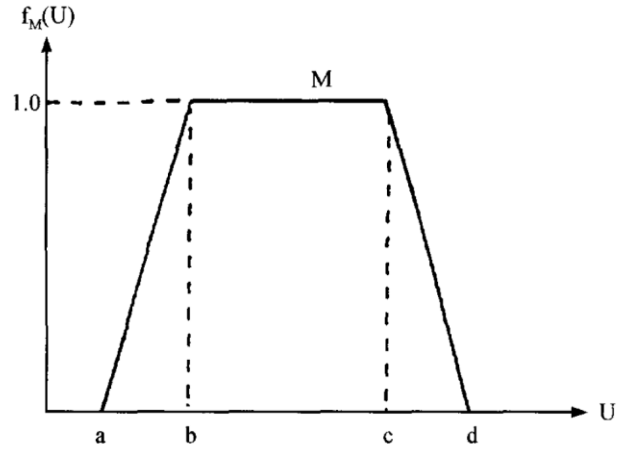


Figure 5.16: A trapezoidal fuzzy number M

Chen (1997) introduced a defuzzification method of trapezoidal fuzzy numbers (Chen 1994; Chen 1996; Kaufmann and Gupta 1988). Chen (1997) considered a trapezoidal fuzzy number M shown in Figure 5.16, where “e” was a defuzzification value of the trapezoidal fuzzy number M from Figure 5.17, it could be seen that;

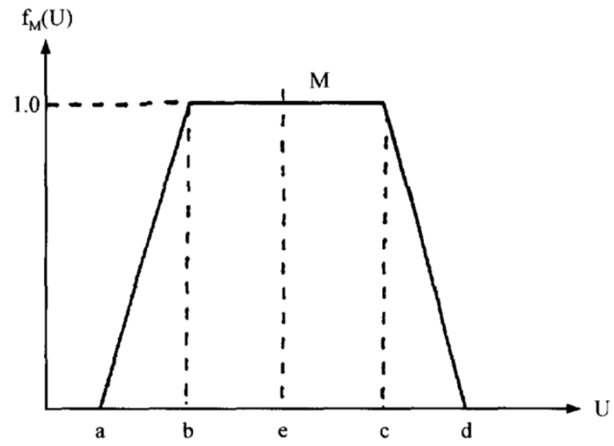


Figure 5.17: Defuzzification of a fuzzy number M

$$
\begin{aligned}
&(e-b)(1)+\tfrac{1}{2}(b-a)(1)=(c-e)(1)+\tfrac{1}{2}(d-c)\\
&\Rightarrow (e-b)+\tfrac{1}{2}(b-a)=(c-e)+\tfrac{1}{2}(d-c)\\
&\Rightarrow (e-b)-(c-e)=\tfrac{1}{2}(d-c)-\tfrac{1}{2}(b-a)\\
&\Rightarrow 2e=\frac{d-c-b+a}{2}+\frac{2b+2c}{2}\\
&\Rightarrow 2e=\frac{a+b+c+d}{2}\\
&\Rightarrow e=\frac{a+b+c+d}{4}.
\end{aligned}
$$

(Equation 5.4)

Chen (1997) and Yener (2007) considered the membership functions of the linguistic terms "very low", "low", "medium", "high", and "very high" shown in Figure 5.18, where the linguistic terms and their corresponding quadruple representations of fuzzy numbers were shown in Table 5.1.

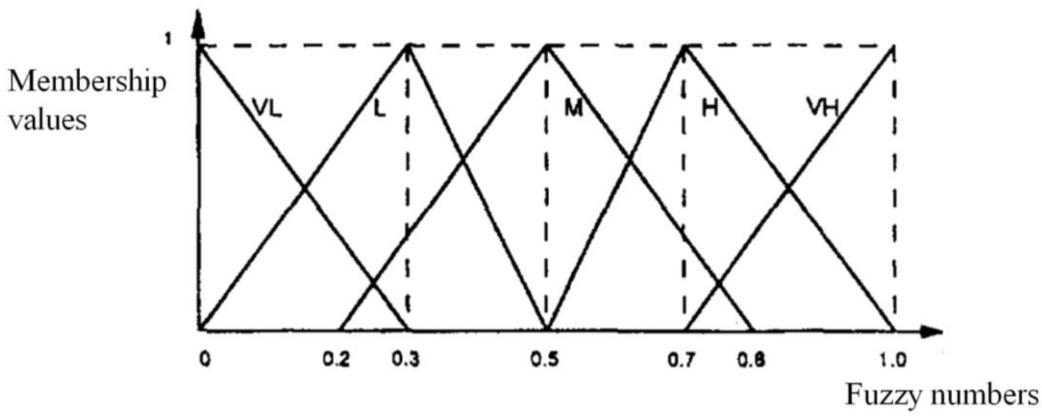


Figure 5.18: Membership functions for linguistic values

Table 5.1: Linguistic terms and their corresponding fuzzy numbers

Linguistic terms	**Fuzzy numbers**
Very low (VL)	(0,0,0,0.3)
Low (L)	(0,0.3,0.3,0.5)
Medium (M)	(0.2,0.5,0.5,0.8)
High (H)	(0.5,0.7,0.7,1)
Very high (VH)	(0.7,1,1,1)

By applying Equation 5.4 above, the defuzzified values of the fuzzy numbers shown in Table 5.1 can be evaluated as follows:

(1) The defuzzified value of the fuzzy number **"very low"** is equal to:

$$\frac{0 + 0 + 0 + 0.3}{4} = 0.075.$$

(2) The defuzzified value of the fuzzy number **"low"** is equal to:

$$\frac{0 + 0.3 + 0.3 + 0.5}{4} = 0.275.$$

(3) The defuzzified value of the fuzzy number **"medium"** is equal to:

$$\frac{0.2 + 0.5 + 0.5 + 0.8}{4} = 0.5.$$

(4) The defuzzified value of the fuzzy number **"high"** is equal to:

$$\frac{0.5 + 0.7 + 0.7 + 1}{4} = 0.725.$$

(5) The defuzzified value of the fuzzy number **"very high"** is equal to:

$$\frac{0.7 + 1 + 1 + 1}{4} = 0.925.$$

5.8 Formation of the fuzzy rules

In the previous chapter, as a result of the questionnaire survey, 1029 respondents achieved to submit the questionnaire form and out of 1029, 180 respondents fully completed the survey. In the questionnaire survey, data was collected from respondents by linguistic terms as “low, medium, high” for observable variables affecting "Safety Performance of Construction Sites”.

In this part, the “Mamdani-style if-and-then fuzzy rules” were established for all (168) observable variables according to the expert judgement (face-to-face interviews made with 15 construction safety professionals having considerable experience at construction sites):

- Rule#1: If the variable’s “Probability of an incident” is low and the variable’s “Impact of an incident” is low, then the variable’s effect on "Safety Performance of Construction Sites" is very low.
- Rule#2: If the variable’s “Probability of an incident” is low and the variable’s “Impact of an incident” is medium, then the variable’s effect on "Safety Performance of Construction Sites" is low.
- Rule#3: If the variable’s “Probability of an incident” is low and the variable’s “Impact of an incident” is high, then the variable’s effect on "Safety Performance of Construction Sites" is medium.
- Rule#4: If the variable’s “Probability of an incident” is medium and the variable’s “Impact of an incident” is low, then the variable’s effect on "Safety Performance of Construction Sites" is low.
- Rule#5: If the variable’s “Probability of an incident” is medium and the variable’s “Impact of an incident” is medium, then the variable’s effect on "Safety Performance of Construction Sites" is medium.
- Rule#6: If the variable’s “Probability of an incident” is medium and the variable’s “Impact of an incident” is high, then the variable’s effect on "Safety Performance of Construction Sites" is high.

- Rule#7: If the variable’s “Probability of an incident” is high and the variable’s “Impact of an incident” is low, then the variable’s effect on "Safety Performance of Construction Sites" is medium.
- Rule#8: If the variable’s “Probability of an incident” is high and the variable’s “Impact of an incident” is medium, then the variable’s effect on "Safety Performance of Construction Sites" is high.
- Rule#9: If the variable’s “Probability of an incident” is high and the variable’s “Impact of an incident” is high, then the variable’s effect on "Safety Performance of Construction Sites" is very high.

According to the determined fuzzy rules (elicited from expert judgement) above, a decision table was formed as similar to Han (2005) and Dikmen et al. (2007) to demonstrate the variable’s effect on “Safety Performance of Construction Sites" in the Table 5.2 below.

Table 5.2: Decision table of variable’s effect on "Safety Performance of Construction Sites"

Variable’s Probability of an incident		Variable’s Impact of an incident: Low	Medium	High
	High	**Medium**	**High**	**Very High**
	Medium	**Low**	**Medium**	**High**
	Low	**Very Low**	**Low**	**Medium**

5.9 Linguistic terms, membership functions and defuzzification operation

A similar methodology that Chen (1997) and Yener (2007) used was adopted in this study in the utilization of fuzzy technique. In the questionnaire form, data (the variable's "probability of an incident" and the variable's "impact of an incident") were gathered as linguistic values as "low, medium and high". Combination of trapezoidal and triangular membership functions were selected as shown in Figure 5.18 and corresponding fuzzy numbers were selected as shown in Table 5.1. These linguistic terms were then defuzzified into concrete numbers as similar to the methodology used by Chen (1997) and Yener (2007) according to the Equation 5.4 by using fuzzy set theory.

By applying Equation 5.4, the defuzzified values of the fuzzy numbers shown in Table 5.1 were evaluated as; (1) The defuzzified value of the fuzzy number "very low" is equal to: 0,075, (2) The defuzzified value of the fuzzy number "low" is equal to: 0,275, (3) The defuzzified value of the fuzzy number "medium" is equal to: 0,500, (4) The defuzzified value of the fuzzy number "high" is equal to: 0,725, (5) The defuzzified value of the fuzzy number "very high" is equal to: 0,925. Linguistic terms, corresponding fuzzy numbers and crisp values were shown in Table 5.3.

Table 5.3: Linguistic terms, corresponding fuzzy numbers and crisp values

Linguistic terms	**Fuzzy numbers**	**Crisp values**
Very low (VL)	(0,0,0,0.3)	0,075
Low (L)	(0,0.3,0.3,0.5)	0,275
Medium (M)	(0.2,0.5,0.5,0.8)	0,500
High (H)	(0.5,0.7,0.7,1)	0,725
Very high (VH)	(0.7,1,1,1)	0,925

5.10 Chapter summary

This chapter explained the theoretical revision of fuzzy set theory, data collection and preparation for analysis by fuzzy operations in detail. Firstly the basics of fuzzy set theory were presented. Although the presented material only covered a part of the body of fuzzy set theory and fuzzy techniques in general, it was designed for the reader to understand the conceptual framework of the fuzzy methodologies to be implemented in the rest of this study.

Secondly, data collection and preparation for analysis by fuzzy operations were explained in detail. As a data collection tool, a questionnaire was administered to construction companies with sites. As explained in the previous chapter, in the questionnaire survey, data was collected from respondents by linguistic terms as "low, medium, high" for observable variables affecting "Safety Performance of Construction Sites".

Thirdly, the formation of Mamdani-style if-and-then fuzzy rules according to the expert judgement (face-to-face interviews made with 15 construction safety professionals having considerable experience at construction sites) was explained. In order to perform fuzzy inference, rules, which connect input variables to output variables in 'IF ... and… THEN ...' form, were used to describe the desired system response in terms of linguistic terms rather than mathematical formulae. In this study, the form of Mamdani-style fuzzy rules (Mamdani and Assilian 1975) was implemented due to the advantages of the Mamdani's approach, being the most popular in the literature, also being intuitive, having widespread acceptance, and well-suited to human input (Kaur and Kaur 2012).

Finally, the adopted methodology in the utilization of fuzzy technique (selection of linguistic terms, fuzzy membership functions, and defuzzification procedure) was explained. According to the selected triangular and trapezoidal fuzzy membership functions, the linguistic terms were defuzzified into concrete numbers as similar to Chen (1997) and Yener (2007) according to the Equation 5.4 by using fuzzy set theory**.**

After gaining the concrete numbers from this chapter, the crisp data outputs became ready for utilization and analysis in the development and validation of the multidimensional safety performance model through Structural Equation Modeling.

CHAPTER 6

PROPOSAL OF A SAFETY PERFORMANCE MODEL IN CONSTRUCTION SITES AND DETERMINATION OF HYPOTHESES BASED ON THIS MODEL

6.1 Introduction

This chapter will present the proposal of a safety performance model and the determination of the hypotheses based on this model.

6.2 Preparation of the preliminary research model

As previously mentioned, a total of 98 observable variables in 16 latent dimensions affecting safety performance of construction sites were achieved through literature review and expert opinions. After determining the observable variables and latent dimensions affecting safety performance of construction sites, a preliminary safety performance model was prepared and the hypotheses based on this model were determined as bellows.

After a thorough literature review, a preliminary research model was proposed in Figure 6.1 as belows:

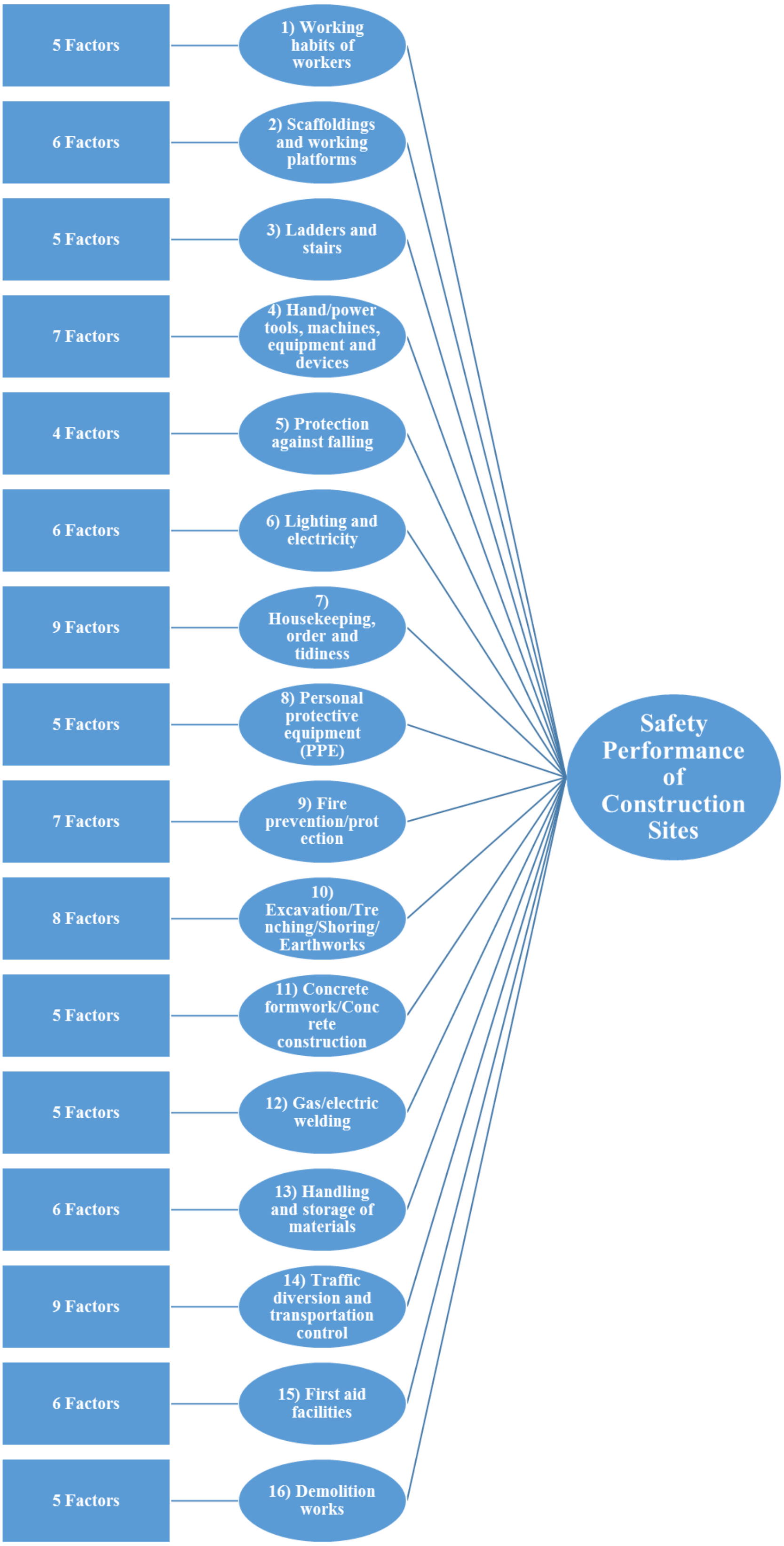


Figure 6.1: Preliminary safety performance model

6.3 Determination of the hypotheses according to preliminary research model

After a thorough literature review, a preliminary research model was proposed. 17 different hypotheses (H1-17) were determined according to the preliminary research model as follows:

H1: A model consisting of 16 latent factors (latent dimensions) were designed in order to measure their effects (weights) on safety performance of construction sites. 16 latent factors (latent dimensions) ("Working habits of workers", "Scaffoldings and working platforms", "Ladders and stairs", "Hand/power tools, machines, equipment and devices", "Protection against falling", "Lighting and electricity", "Housekeeping, order and tidiness", "Personal protective equipment (PPE)", "Fire prevention/protection", "Excavation/Trenching/Shoring/ Earthworks", "Concrete formwork /Concrete construction", "Gas/electric welding", "Handling and storage of materials", "Traffic diversion and transportation control", "First aid facilities", and "Demolition works" predict "Safety performance of construction sites".

H2: The appropriateness of "Working habits of workers" has a positive direct effect on "Safety performance of construction sites".

H3: The conformity of "Scaffoldings and working platforms" has a positive direct effect on "Safety performance of construction sites".

H4: The conformity of "Ladders and stairs" has a positive direct effect on "Safety performance of construction sites".

H5: The conformity of "Hand/power tools, machines, equipment and devices" has a positive direct effect on "Safety performance of construction sites".

H6: The propriety of "Protection against falling" has a positive direct effect on "Safety performance of construction sites".

H7: The conformity of "Lighting and electricity" has a positive direct effect on "Safety performance of construction sites".

H8: The propriety of "Housekeeping, order and tidiness" has a positive direct effect on "Safety performance of construction sites".

H9: The conformity of "Personal protective equipment (PPE)" has a positive direct effect on "Safety performance of construction sites".

H10: The propriety of "Fire prevention/protection" has a positive direct effect on "Safety performance of construction sites".

H11: The propriety of "Excavation/Trenching/Shoring/Earthworks" has a positive direct effect on "Safety performance of construction sites".

H12: The propriety of "Concrete formwork/Concrete construction" has a positive direct effect on "Safety performance of construction sites".

H13: The conformity of "Gas/electric welding" has a positive direct effect on "Safety performance of construction sites".

H14: The propriety of "Handling and storage of materials" has a positive direct effect on "Safety performance of construction sites".

H15: The appropriateness of "Traffic diversion and transportation control" has a positive direct effect on "Safety performance of construction sites".

H16: The conformity of “First aid facilities” has a positive direct effect on “Safety performance of construction sites”.

H17: The propriety of “Demolition works” has a positive direct effect on “Safety performance of construction sites”.

6.4 Development of the final research model

After making the face-to-face interviews about the preliminary questionnaire form with 15 construction safety professionals, conducting additional literature review, and figuring out a total of 168 observable variables in 16 latent dimensions affecting safety performance of construction sites, a final safety performance model have been formed and the research hypotheses were determined accordingly. Final research model was proposed in Figure 6.2 as follows:

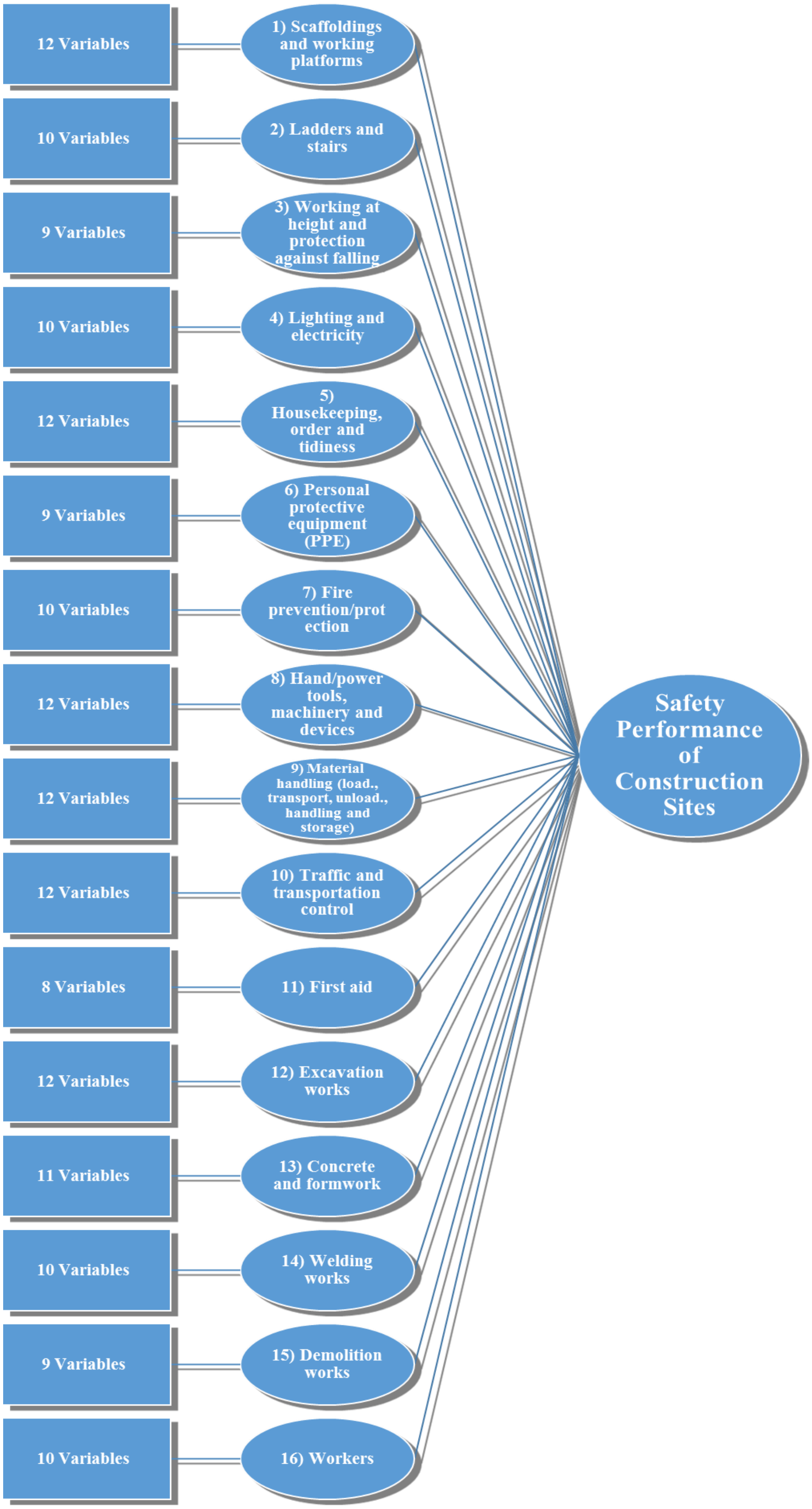


Figure 6.2: Proposed final safety performance model

6.5 Determination of the hypotheses according to final research model

According to the final research model, 17 different hypotheses (H1-17) were determined as follows:

H1: A model consisting of 16 latent dimensions were designed in order to measure their effects (weights) on safety performance of construction sites. 16 latent dimensions (“Scaffoldings and working platforms”, “Ladders and stairs”, “Working at height and protection against falling”, “Lighting and electricity”, “Housekeeping, order and tidiness”, “Personal protective equipment (PPE)”, “Fire prevention/protection”, “Hand/power tools, machinery and devices”, “Material handling (loading, transport, unloading, handling and storage)”, “Traffic and transportation control”, “First aid”, “Excavation works”, “Concrete and formwork”, “Welding works”, “Demolition works”, and “Workers”) predict “Safety performance of construction sites”.

H2: The conformity of “Scaffoldings and working platforms” has a positive direct effect on “Safety performance of construction sites”.

H3: The conformity of “Ladders and stairs” has a positive direct effect on “Safety performance of construction sites”.

H4: The appropriateness of “Working at height and protection against falling” has a positive direct effect on “Safety performance of construction sites”.

H5: The propriety of “Lighting and electricity” has a positive direct effect on “Safety performance of construction sites”.

H6: The conformity of “Housekeeping, order and tidiness” has a positive direct effect on “Safety performance of construction sites”.

H7: The propriety of “Personal protective equipment (PPE)” has a positive direct effect on “Safety performance of construction sites”.

H8: The conformity of “Fire prevention/protection” has a positive direct effect on “Safety performance of construction sites”.

H9: The propriety of “Hand/power tools, machinery and devices” has a positive direct effect on “Safety performance of construction sites”.

H10: The propriety of “Material handling (loading, transport, unloading, handling and storage)” has a positive direct effect on “Safety performance of construction sites”.

H11: The conformity of “Traffic and transportation control” has a positive direct effect on “Safety performance of construction sites”.

H12: The propriety of “First aid” has a positive direct effect on “Safety performance of construction sites”.

H13: The appropriateness of “Excavation works” has a positive direct effect on “Safety performance of construction sites”.

H14: The conformity of “Concrete and formwork” has a positive direct effect on “Safety performance of construction sites”.

H15: The propriety of “Welding works” has a positive direct effect on “Safety performance of construction sites”.

H16: The propriety of “Demolition works” has a positive direct effect on “Safety performance of construction sites”.

H17: The conformity of "Workers" has a positive direct effect on "Safety performance of construction sites".

6.6 Chapter summary

This chapter presented the proposal of a safety performance model and the determination of the hypotheses based on this model. As previously mentioned, a total of 98 observable variables in 16 latent dimensions affecting safety performance of construction sites were achieved through literature review and expert opinions. After determining the observable variables and latent dimensions affecting safety performance of construction sites, a preliminary safety performance model was prepared and the hypotheses based on this model were determined. After making the face-to-face interviews about the preliminary questionnaire form with 15 construction safety professionals, conducting additional literature review, and figuring out a total of 168 observable variables in 16 latent dimensions affecting safety performance of construction sites, a final safety performance model have been formed and the research hypotheses were determined accordingly.

CHAPTER 7

STATISTICAL ANALYSES OF THE ACQUIRED DATA

7.1 Introduction

In this chapter, in-depth statistical analysis of the acquired data will be explained. IBM SPSS Statistics computer program will be used for the analyses. In search of the characteristics of the respondents, descriptive statistical analyses will be performed according to the information obtained from the respondents. Accordingly, the mean, standard error, median, mode, standard deviation, sample variance, kurtosis, skewness, range, minimum, and maximum values of the gathered data will be mentioned. Some important descriptive information of the respondents will be presented in the following parts.

7.2 Descriptive statistics

As a result of the questionnaire survey made between 07.05.2014 and 15.11.2014, 1029 respondents have been submitted the questionnaire form. Out of 1029, 180 respondents fully completed the survey. Average time spent in a survey for each respondents (180 full responses) was approximately 43 minutes.

7.2.1 Respondents' working sectors

According to the survey results, 62.2% of the respondents were working for private, whereas 35.6% were working for public sector. Respondents' working sectors were presented in Table 7.1 and Figure 7.1.

Table 7.1: Respondents' working sectors

Which sector are you working for?		
Answer Options	**Response Percent**	**Response Count**
Public	35,6%	64
Private	62,2%	112
Other (please specify)	2,2%	4
	answered question	**180**
	skipped question	**0**

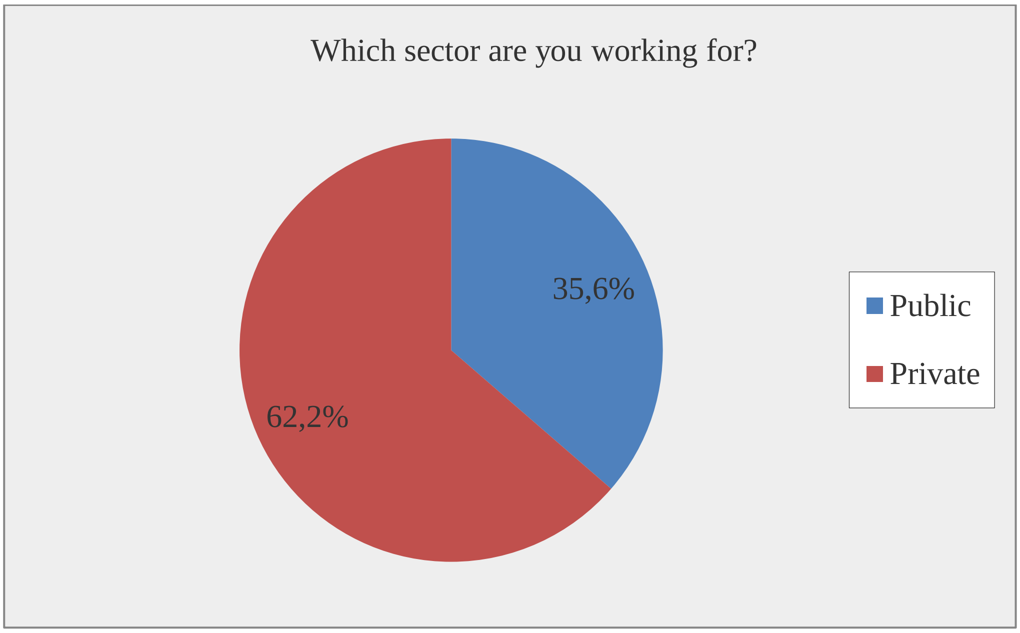


Figure 7.1: Respondents' working sectors

7.2.2 Respondents’ working parties

Survey results indicated that, 53.9% of the respondents were working for owner, 27.2% were working for contractor, and 12.2% were working for consultant. Respondents’ working parties were presented in Table 7.2 and Figure 7.2.

Table 7.2: Respondents’ working parties

Which party are you working for?		
Answer Options	**Response Percent**	**Response Count**
Owner	53,9%	97
Contractor	27,2%	49
Consultant	12,2%	22
Other (please specify)	6,7%	12
	answered question	**180**
	skipped question	**0**

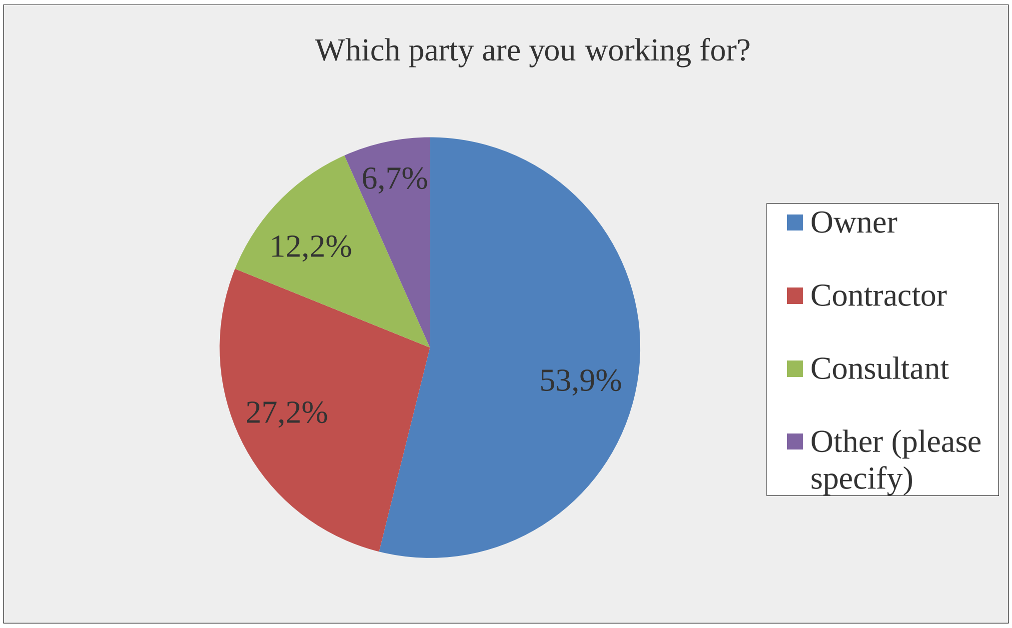


Figure 7.2: Respondents’ working parties

7.2.3 Respondents' positions at their companies

According to the survey results, 56.1% of the respondents were working as engineer-supervisor, 28.3% were working as manager, 7.2% were working as owner, and 1.7% were working as technician-foreman position at their companies. Respondents' positions at their companies were given in Table 7.3 and Figure 7.3.

Table 7.3: Respondents' positions at their companies

What is your position at your company?		
Answer Options	**Response Percent**	**Response Count**
Owner	7,2%	13
Manager	28,3%	51
Engineer-Supervisor	56,1%	101
Technician-Foreman	1,7%	3
Other (please specify)	6,7%	12
	answered question	**180**
	skipped question	**0**

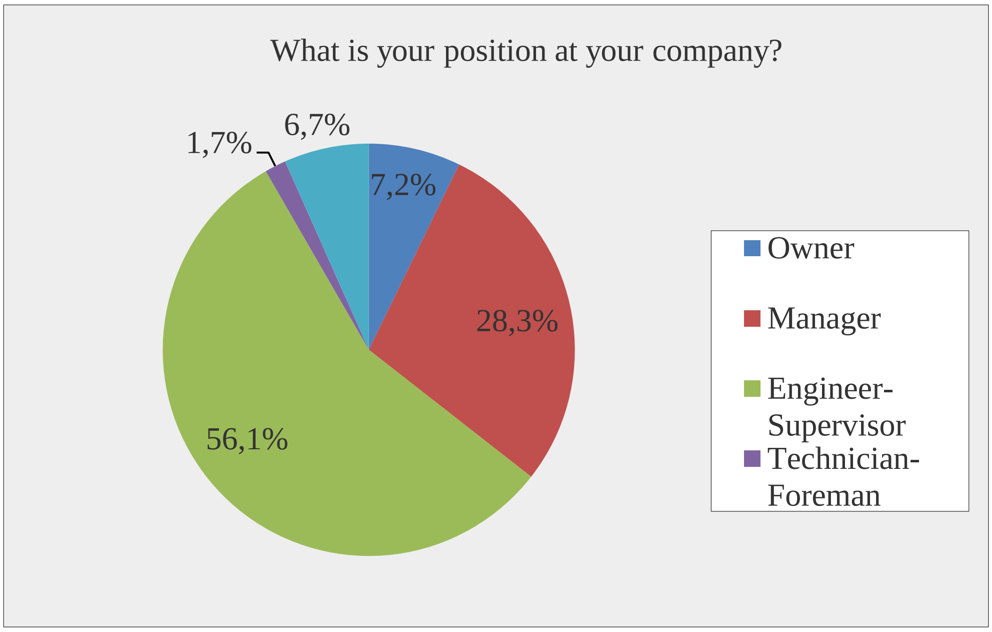


Figure 7.3: Respondents' positions at their companies

7.2.4 Respondents' possession of occupational safety expertise certificates

Survey results showed that, 40.6% of the respondents possessed occupational safety expertise certificate, comprised of 17.8% having Class A, 15.6% having Class C, and 7.2% having Class B. Respondents' possession of occupational safety expertise certificates were presented in Table 7.4 and Figure 7.4.

Table 7.4: Respondents' possession of occupational safety expertise certificates

Do you own occupational safety expertise certificate?		
Answer Options	**Response Percent**	**Response Count**
No	59,4%	107
Yes, Class A	17,8%	32
Yes, Class B	7,2%	13
Yes, Class C	15,6%	28
	answered question	**180**
	skipped question	**0**

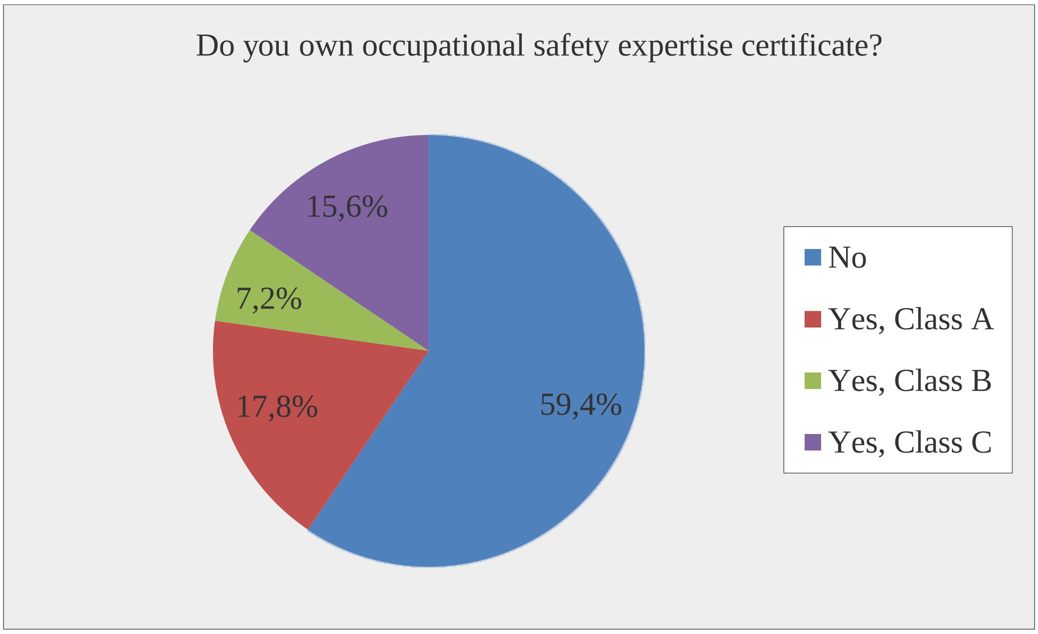


Figure 7.4: Respondents' possession of occupational safety expertise certificates

7.2.5 Areas of expertise of current companies (respondents work for)

The areas of expertise of the companies (respondents currently working for) were mainly on Building Construction (45.6%), Industrial Facilities (30.6%), Infrastructure (28.8%), Transport (21.7%), and Hydraulic Structures (15.0%). Table 7.5 and Figure 7.5 showed the distribution of companies (respondents' current working for) in terms of their areas of expertise.

Table 7.5: Areas of expertise of current companies (respondents work for)

Areas of expertise of company you work for?		
Answer Options	**Response Percent**	**Response Count**
Building Construction	45,6%	82
Transport	21,7%	39
Infrastructure	28,9%	52
Hydraulic Structures	15,0%	27
Industrial Facilities	30,6%	55
Other (please specify)	31,7%	57
	answered question	**180**
	skipped question	**0**

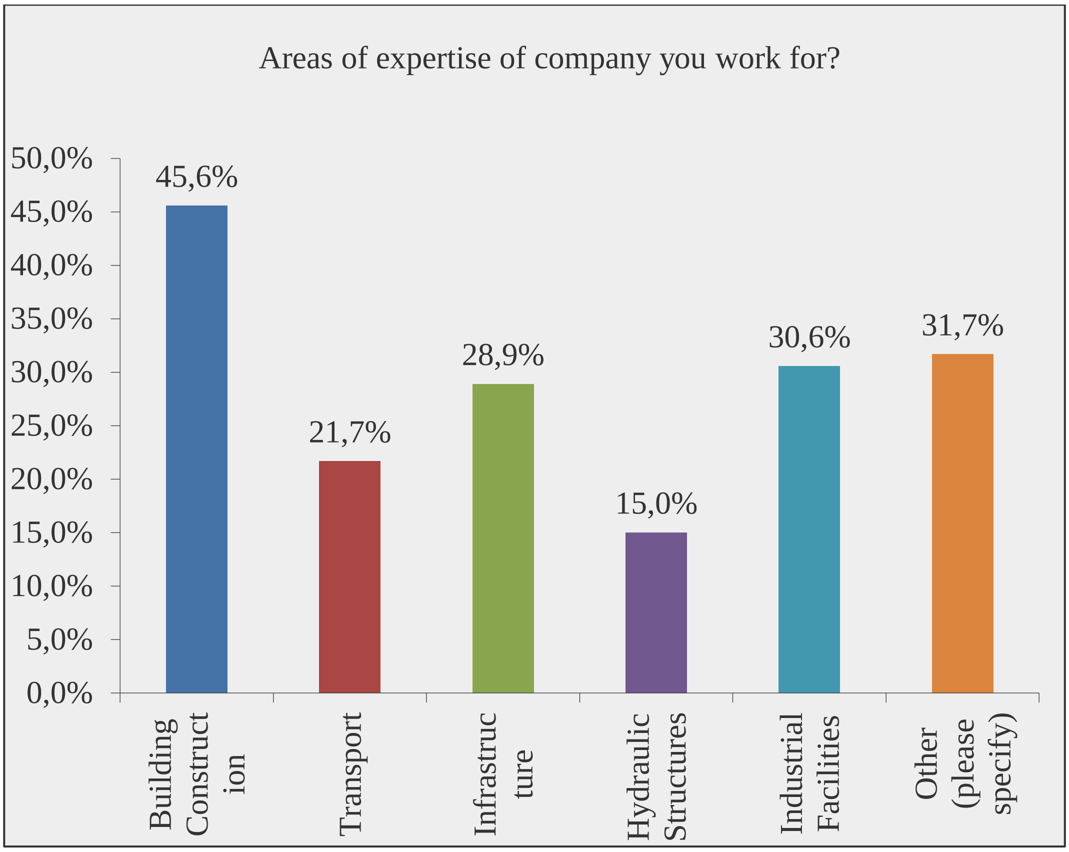


Figure 7.5: Areas of expertise of current companies (respondents work for)

7.2.6 Experience of the respondents (in their current companies)

The survey results showed that, 53.9% of the respondents had 0-5 years, 23.3% had 6-10 years, 9.4% had 11-15 years, 5.6% had 16-20 years, 6.1% had 21-30 years, 6.1% had 21-30 years, and 1.7% had 31-34 years of experience in companies they have been working for. The average experience of the respondents in their current companies was 6.71 years. Experience of the respondents (in their current companies) were given in terms of years in Table 7.6 and Figure 7.6.

Table 7.6: Experience of the respondents (in their current companies)

How many years have you been working for this company?		
Answer Options	**Response Percent**	**Response Count**
0-5	53,9%	**97**
6-10	23,3%	**42**
11-15	9,4%	**17**
16-20	5,6%	**10**
21-30	6,1%	**11**
31-40	1,7%	**3**
	answered question	**180**
	skipped question	**0**

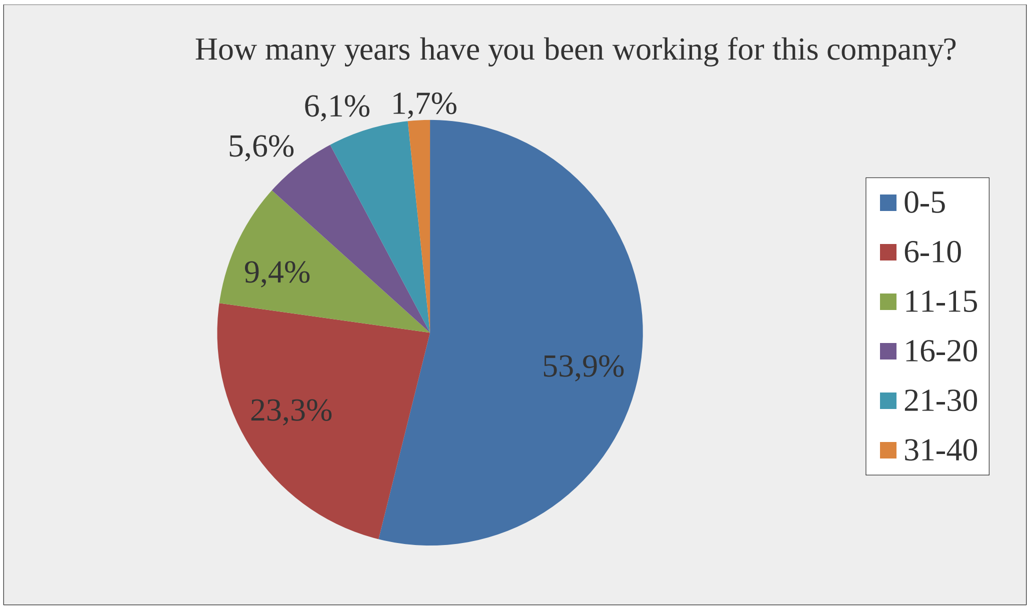


Figure 7.6: Experience of the respondents (in their current companies)

7.2.7 Experience of the respondents (in the construction industry)

According to the survey results, 25.0% of the respondents had 0-5 years, 27.8% had 6-10 years, 10.6% had 11-15 years, 13.3% had 16-20 years, 12.8% had 21-30 years, 8.9% had 31-40 years, and 1.7% had 41-50 years of experience in construction industry. The average experience of the respondents in the construction industry was 12.26 years. Experience of the respondents in the construction industry in terms of years were presented in Table 7.7 and Figure 7.7.

Table 7.7: Experience of the respondents (in the construction industry)

How many years have you been working in construction industry?		
Answer Options	**Response Percent**	**Response Count**
0-5	25,0%	**45**
6-10	27,8%	**50**
11-15	10,6%	**19**
16-20	13,3%	**24**
21-30	12,8%	**23**
31-40	8,9%	**16**
41-50	1,7%	**3**
	answered question	**180**
	skipped question	**0**

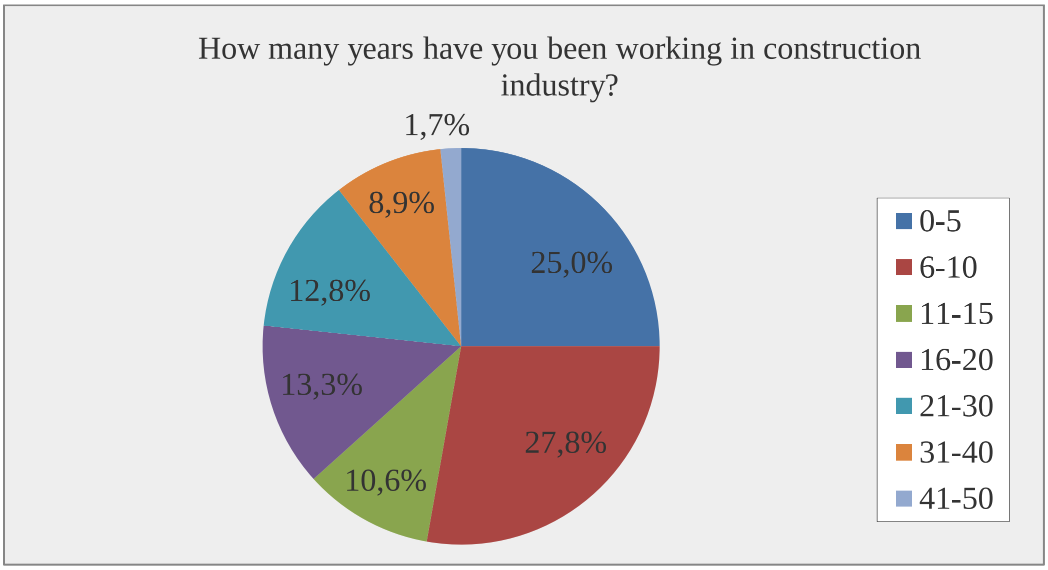


Figure 7.7: Experience of the respondents (in construction industry)

7.3 Chapter summary

In this chapter, in-depth statistical analysis of the acquired data were explained. IBM SPSS Statistics computer program was used for the analyses. In search of the characteristics of the respondents, descriptive statistical analyses were performed according to the information obtained from the respondents. Accordingly, the mean, standard error, median, mode, standard deviation, sample variance, kurtosis, skewness, range, minimum, and maximum values of the gathered data were calculated by IBM SPSS Statistics can be found in Appendix D. Respondents' working sectors, working parties, positions at their companies, possession of occupational safety expertise certificates, areas of expertise of current companies respondents work for, experience of the respondents in their current companies, and experience of the respondents in the construction industry were presented as important descriptive information of the respondents.

CHAPTER 8

ANALYSIS AND DEVELOPMENT OF A MULTIDIMENSIONAL SAFETY PERFORMANCE MODEL FOR CONSTRUCTION SITES BY STRUCTURAL EQUATION MODELING (SEM)

8.1 Introduction

In this chapter, the basics of structural equation modeling will be presented. Although the presented material only will cover a part of the body of structural equation modeling in general, it will be designed for reader to understand the conceptual framework of the SEM methodologies and processes to be implemented in the rest of this study.

Brief information about structural equation modeling and its assumptions, advantages, terms, components, processes, applications in the construction industry, application to the current study and selected software package of SEM (LISREL) will be mentioned.

Then, for the preparation of the SEM analyses, the choice of the type of the input matrix, estimation techniques, analysis approach, selection of goodness of fit indices, data screening (missing values), examination of univariate and multivariate normality, and sample size requirements will be explained in a detailed manner. After describing the preparation of the analyses for SEM, the assessment of the measurement model by SEM will be presented inclusive of content validity, unidimensionality, convergent validity, goodness of fit, reliability (internal consistency and composite reliability), and discriminant validity testings. Analysis of the measurement model will be carried out using factor analysis by first-order and second-order confirmatory factor analysis (CFA) for the assessment of unidimensionality, convergent validity, reliability, and discriminant validity. After achieving the validity of the measurement model, the equations calculated by LISREL corresponding to the measurement model (associations between the latent dimensions and respective observable variables) and the structural model (associations between first-order and second-order latent factors) will be presented. Finally, the assessment of the structural model including the testing of hypothesized second-order factor structural model, testing the research hypotheses according to the testing results of the structural model performed by structural equation modeling (SEM) as a confirmatory assessment of structural validity will be explained comprehensively.

8.2 Structural equation modeling (SEM)

Structural equation modeling (SEM) was utilized to achieve objectives of the current thesis proposal to study the relationships between determinants of safety performance, and to develop and validate a multidimensional safety performance model.

Structural equation modeling is a large set of statistical techniques based on general linear model that examines a set of relations between one or more independent variables (IVs) and one or more dependent variables (DVs) at the same time. IVs and DVs can either be measured variables (directly observed), or latent variables (unobserved) (Ullman 2006). SEM grows out of and serves similar purposes of multiple regression but in a more powerful way. It has more flexible assumptions than multiple regression, particularly allowing interpretation even in the face of multicollinearity (Garson 2012). SEM is also referred to as causal modeling, causal analysis, simultaneous equation modeling, and analysis of covariance structures, path analysis, or confirmatory factor analysis (Kline 1998; Mueller 1996; Garver and Mentzer 1999).

8.3 Assumptions of structural equation modeling

For proper application of SEM, at least three basic assumptions should be met: multivariate normality, selection of covariance matrix, and sufficient sample size (Crowley and Fan 1997). Maximum likelihood estimate (MLE) is the most common estimation method of SEM. MLE is sensitive to departure of normality. When data are significantly non-normal, other estimation methods which do not require normality should be used or the Satorra-Bentler scaled chi-square which corrects the test statistics to take into account of non-normality should be used. Covariance matrix should be analyzed rather than correlation matrix because statistical theories of estimation methods of SEM are derived from covariance matrix (Hung, 2012).

Sample size should be sufficiently large. If the variables are reliable and the effects are strong and the model not overly complex, smaller samples will suffice (Bearden et al. 1982; Bollen 1990). Although there is no fixed rule, Crowley and Fan (1997) proposed a number of 200; Jayaram et al. (2004) suggested a number of 150 as the minimum sample size. According to Crowley and Fan (1997); Bentler and Chou (1987), taking into account of the model complexity and number of parameters to be estimated, each estimated parameter should have 5 to 10 participants to support. Nunnally (1967) suggested that in SEM estimation 'a good rule is to have at least 10 times as many subjects as variables'. Tanaka (1987) argued that sample size should be dependent on the number of estimated parameters (the latent variables and their correlations) rather than on the total number of indicators. Bentler (1989) suggested a 5:1 ratio of sample size to number of free parameters. Boomsma (1982) suggested using a ratio r=p/k (where r: ratio of indicators to latent variables, p:number of indicator variables, k: number of latent variables) and his simulations resulted for r=2 would require a sample size of at least 400 and for r=4 would require a sample size of at least 100 for adequate analysis; and, Marsh et al. (1988), Marsh et al. (1996), Marsh et al. (1998) ran 35,000 Monte Carlo simulations on LISREL Confirmatory Factor

Analysis (CFA), yielding data that suggested that: r=2 would require a sample size of at least 400; r=3 would require a sample size of at least 200; r=12 would require a sample size of at least 50 (Westland 2010). SEM models can perform well even with small samples 50 to 100. If the measurement is strong (3 or 4 indicators per factor, and good reliabilities), and the structural path model not overly complex, then samples of size 50 or 100 can be plenty (Iacobucci 2010). In terms of bias reduction and even just getting the model to run, with "three or more indicators per factor, a sample size of 100 will usually be sufficient for convergence," and a sample size of 150 "will usually be sufficient for a convergent and proper solution" (Anderson and Gerbing 1984). The assumptions and sample size requirements will be checked and conformed in order to employ SEM in this study.

8.4 Advantages of structural equation modeling

SEM was selected as an analysis and testing tool for this study because of its unique features over other multivariate techniques:

- SEM provides the researchers with the possibility of studying problems which are neither observable nor quantifiable through the concept of latent variables. A latent variable is a hypothesized and unobserved concept that can only be approximated by observable or measurable variables collected from survey or experiment. SEM allows testing of hypothesis at the construct level with adequate accuracy. That is, while other methods deal only with measured observed variables, SEM enables creation and estimation of latent variables underlying the observed variables, and also examination of their interrelationships (Jackson et al. 2005; Ullman 2006; Bentler 2006; Byrne 2006, and Garson 2008).

- SEM can examine a series of separate, but interdependent, multiple regression equations simultaneously by specifying the structural model.

SEM enables the analysis of highly complex models containing diverse types of relations and high number of variables. Direct and indirect causal effects and covariances among variables can be investigated instead of studying all variables under the same unique level. That is, dependent variables can also act as the predictors of other variables. Other comparable statistic methods allow for limited number of hypothesis to be evaluated (Biddle and Marlin 1987; Byrne 2006; and Bentler 2006).

- In contrast to ordinary regression methods, SEM takes into consideration the possible errors in measurement of observed variables. The assumption of perfect measurement of variables is not a realistic approach and as Byrne (2006) and Ullman (2006) emphasize, it may affect the reliability of analysis and lead to serious inaccuracies, especially when errors are fairly large. Measurement errors can increase model error variance, and lead to biased estimates (Myers 1990; Greene 1990). This shortcoming of alternative methods is eliminated in SEM to take the effects of poorly measured data into account (Bentler 2006).

- SEM takes a confirmatory rather than an exploratory approach to data analysis. This enables the evaluation of hypotheses. Various fit indexes and validity/reliability tests are available for examining the compatibility of the developed models and assumed relationships with the sample data (Schreiber et al. 2006; Ullman 2006; Byrne 2006; Byrne 2009; and Garson 2008). An a priori theoretical model can be tested with empirical data by SEM. In contrast, most other multivariate techniques are descriptive and exploratory in nature, making them less appropriate for model testing (Crowley and Fan 1997).

8.5 Terms of structural equation modeling

Path Diagrams: Path diagrams are visual representations of assumed and analyzed structural equation models. Drawn paths should exactly correspond to the equations included in analysis.

Observed Variables: Observed variables are also referred as measured variables, manifest variables, indicators, and they are tangible variables. Conventionally, observed variables are shown by rectangles in drawn path diagrams.

Latent Variables: One of the advantages of SEM over other techniques is the concept of latent variables used to indicate intangible concepts which cannot be measured directly. The magnitudes of such factors are measured through the hypothesized effects of observed variables indicating them. Latent variables are also mentioned as factors, or constructs, and in path diagrams, are conventionally depicted with circles or ovals.

Exogenous Variables: Exogenous variables are also referred as independent variables. These variables are not structurally regressed on other variables. That is, they have effects on other variables (are causes of other variables) but are not affected by other constructs (Schreiber et al. 2006, and Kline 2005). The exogenous constructs are not indicated by any causal (one-way) arrow though they can be correlated with other independent variables depicted with two-way arrows. The exogenous variables are the elements of the vector variable which is conventionally indicated by ξ ("ksi") (Garson 2008; Bentler 2006).

Endogenous Variables: Are also referred as dependent variables and mediating variables. These variables can be defined through the regression of other variables. They are influenced by either independent variables or other dependent variables and can have effects on other endogenous variables in the model (Schreiber et al. 2006; Kline 2005). The magnitude of these variables can be estimated by the sizes of their influencing variables; however, these dependent variables cannot be correlated with each other through two-headed arrows. The endogenous variables are the elements of the column vector variable which is conventionally indicated by η ("eta") (Garson 2008; Bentler 2006).

Standardized Path Coefficients: Standardized estimates are used when not all variables have interpretable metrics, or when the measurement units of model variables differ from each other; for example, when the cause factor is measured by "day" units and the effect factor is measured by "dollars". SEM-based software packages generally provide the standardized solutions in which all variables are standardized to have unit variances with mean of zero. Estimated standardized path coefficient among two factors (also noted as "Standardized Structural Coefficients") shows the number of standard units that dependent factor will increases due to each unit increase in its influencing factor (Garson 2008; Bentler 2006).

Figure 8.1 shows the general representation (suggested by Byrne (2006)) of a SEM model in which; V_i: Observed (measured) Variables, F_i: Latent Factors, E_i: Random Measurement Errors of Observed Variables, D2: Errors in Prediction of F2, →: Causality, ↕ : Correlation or Covariance among pairs of Independent Variables.

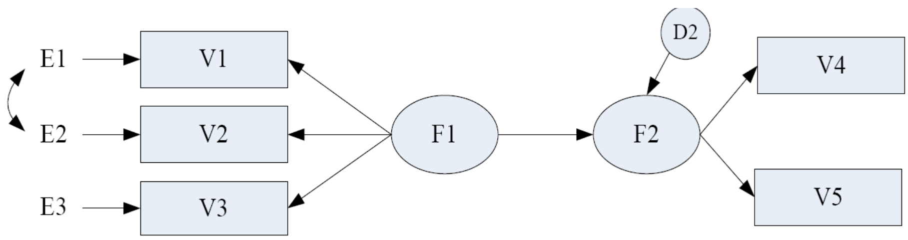


Figure 8.1: A general representation of structural equation model suggested by Byrne (2006)

8.6 Components of structural equation modeling

The analysis process of structural equation models starts with the development of a hypothesized theoretical model based on the underlying theory. This model illustrates all hypothesized relationships between observed variables and latent factors. The general form of SEM consists of two main parts, namely measurement model and structural model (Kline 1998).

The measurement model (also called "Factor Analytic Measurement Model" and "Confirmatory Factor Analysis Model") shows the hypothesized relations between the observed (measured) variables and the latent factors to which they indicate, and is to be tested through Confirmatory Factor Analysis (CFA). In CFA, in contrast to Exploratory Factor Analysis (EFA), researcher has a strong knowledge about the structure of the variables and the hypotheses about these structures are tested statistically. The fit degree of a measurement model indicates the extent to which it's exogenous observed indicators measure the latent factor.

The structural model (also called "Simultaneous Equation Model" and "Construct Model") shows the assumed causal relations among latent factors. The hypothesized construct models are also tested statistically and the path coefficients, which indicate the strength of the assumed relations, are estimated. In this study, it is the structural component of the SEM model which allows for representation of the relationships between "safety performance of construction sites" and its latent dimensions.

In order to test the extent to which the entire model describes the actual data, both hypothesized measurement and structural models are tested step-by-step by various fit indexes and validation tests. A highly fitted model is accepted only if it is theoretically supported (Molenaar et al. 2000; Byrne 2006; Bentler 2006; Schreiber et al. 2006).

8.7 Processes of structural equation modeling

SEM applications typically follow a four-step process (Bollen and Long 1993; Chin et al. 2008).

8.7.1 Step 1: Model specification

This step includes the specification of a conceptual model consisting of hypothesized relationships based on the underlying theory, and drawing of the corresponding equations and diagrams corresponding to the hypothesized relation (Hung 2012).

8.7.2 Step 2: Model identification

Model identification considers the question of whether all the parameters are uniquely defined. An unidentified model may have more than one or even an infinite number of set(s) of parameters that can produce the same covariance matrix. Thus, no unique solution to the problem would exist. When there is unique numerical solution for the specified model, it is considered as identified (Hung 2012).

8.7.3 Step 3: Model estimation

As the model is specified, the parameters should be estimated using appropriate estimation method (Hung 2012). For model estimation, a variety of methods such as maximum likelihood (ML), generalized least squares (GLS), weighted least squares (WLS) or arbitrary distribution free (ADF) and ordinary least squares (OLS) methods can be utilized. The choice depends on the sample size, data distribution, and type of data matrix used as input. ML estimation is the most frequently used estimation method in SEM; however, it requires the data set to be normally distributed. ADF does not require normal distribution; however, it requires a huge data set (> 2,500) to perform well. As suggested by Ullman (2006), “in medium (over 120) to large samples the scaled ML test statistic is a good choice with non-normality or suspected dependence among factors and errors”. If the data set of the study is significantly non-normal and reasonably large, the Satorra-Bentler scaled chi-square may be utilized. This is an adjusted chi-square statistic that attempts to correct for the bias introduced when data are markedly non-normal in distribution (Satorra and Bentler 2001).

8.7.4 Step 4: Model evaluation

After the model is estimated, the fit of the conceptual model to the sample data should be evaluated. This process is conducted through various fit indices. Many model fit indices are available; however, no single fit index is sufficient for a correct assessment of model fitness (Seo et al. 2004).

Testing reliability and validity of the measurement models: Various reliability and validity testes are proposed to verify that data is generally consistent with the hypothesized measurement constructs. In order to examine the reliability of the measurement models, the “internal consistency of constructs”, measuring the same latent variable for the collected data, is tested. For this purpose, the “unidimensionality” and “individual item reliability” are tested for the constructs with more than two indicators. Unidimensionality indicates the degree to which items represent one and only one underlying latent variable (Garver and Mentzer 1999). Commonly, measured variables with standardized factor loadings close or greater than 0.5 are accepted to be unidimensional (Hair et al. 2006). It means that such variables explain a significant portion of the variance in their indicated latent variables. A possible evidence of potential threats to unidimensionality was the number of absolute values above 3 in the matrix of standardized residuals, which might indicate that the model was not satisfactorily estimate the relationship between a given pair of variables (Jöreskog and Sörbom 1993). Also, modification indices above 5 might also be another sign of potential threats to unidimensionality (Anderson and Gerbing 1988; Gefen 2003). Individual reliability of variables, which shows the extent to which distinct indicators for a latent variable belong together (Garson 2008), is accepted to be satisfactory if the "Cronbach's Alpha" coefficients reported for each item is greater than the threshold value of 0.7 recommended by Nunnally (1978), Nunnally and Bernstein (1994) and Hair et al. (2006). The construct validity of the measurement models is examined through "Convergent" and "Discriminant" validity tests. Convergent validity was the extent to which the latent variable correlated to corresponding items designed to measure the same latent variable. Convergent validity was testing if all the items measuring a latent variable cluster together and form a single latent variable. Anderson and Gerbing (1988) stated that convergent validity is satisfied for measurement models whose estimated parameters (factor loadings) are significant in an appropriate level. The evidence of convergent validity was reinforced by the substantial loadings (greater than 0.50) for all items (Hildebrandt 1987; Steenkamp and van Trijp 1991). Hair et al. (2010) recommended that standardized factor loading should be greater than 0.50. In second-order CFA, an additional requirement should be accomplished for assessing convergent validity: the relationships between the first-order factors and the second-order factor should be significant (Benson and Bandalos 1992). The evidence of convergent validity was further strengthened by the good overall fit of the model (Steenkamp and van Trijp 1991). Discriminant validity referred to the principle that the indicators for different constructs should not be so highly correlated as to lead one to conclude that they measure the same thing. Discriminant validity analysis referred to testing statistically whether two measures differed (as opposed to testing convergent validity). The correlations between the measures should be lower than unity in order to achieve discriminant validity.

Testing fitness of the structural models: One of the most widely used fit indices is model chi-square (χ^2) which tests the closeness of fit between the sample covariance matrix and the fitted covariance matrix. A non-significant, small χ^2 value indicates that the observed data are not significantly different from the hypothesized model. However, as formula of computing χ^2 is related to sample size, nearly all models are evaluated as incorrect as sample size increases. For this reason, the ratio of χ^2 to the degrees of freedom (χ^2/dof) has been commonly used as an alternative fit index. If this value is less than 2, the model is a good fit (Ullman 2006; Ullman 2001). Another commonly used fit index is root mean square error of approximation (RMSEA). According to Byrne (2009), RMSEA is "one of the most informative criteria in covariance structure modeling". RMSEA values of less than 0.05 indicate a good fit, whereas values as high as 0.08 indicate a reasonable fit, represent reasonable errors of approximation in the population. Other commonly used fit indices include Comparative Fit Index (CFI), Normed Fit Index (NFI) and Non-normed Fit Index (NNFI). CFI, NFI, and NNFI of 0.95 or greater indicate a good fit (Bryne 2009).

8.8 Application of structural equation modeling in construction industry

Structural Equation Modeling is a widely applied technique in non-experimental research areas in which theory testing techniques are not well developed (Kline 2005). Superiorities of SEM over other statistical techniques and the applicability of its assumptions have caused it to be widely used in Information Technology, Psychology, Sociology, Medical, and Behavioral Sciences.

Lots of construction engineering and management issues are related with measurement of latent factors or observations; therefore, SEM grows as an important methodological tool (Molwus et al. 2013) and an appropriate technique increasingly applied (Molenaar et al. 2000) in construction engineering and management area for development of decision support systems, expert systems, risk analysis, predictive models, etc. These factors may be the reasons for the rapidly increased popularity of the application of SEM in construction engineering and management area over the last years.

For example, Molenaar et al. (2000) developed a SEM model for identification and quantification of factors that affect the dispute potential between project parties. They claimed SEM to be a suitable approach for clarifying the relationships among unobservable factors such as management ability of project parties and dispute potential.

Mohamed (2002) used SEM in examining the relationship between safety climate and safe work behaviour in construction site environment. Islam and Faniran (2005) studied modeling the process of project planning by SEM. Wong and Cheung (2005) examined the relationships between trust and partnering success in construction projects by using SEM. Mohamed (2003), Özorhon et al. (2007), and Özorhon et al. (2008) utilized SEM for testing and analyzing the hypothesized relationships between various factors that may affect performance of international joint venture.

Cheung et al. (2009) utilized SEM to confirm three construct models explored for three dimensions of negotiation, namely “Dispute Sources”, “Negotiator Tactics”, and “Negotiation Outcomes”. The ultimate aim of their research is to examine the conditional application of negotiation tactics with respect to negotiation outcomes and sources of the disputes.

Kim et al. (2009) conducted a study to compare the applicability and suitability of SEM with regression analysis and artificial neural network methods in terms of predicting the performance of any international project. They concludes that SEM was more appropriate for this purpose since it allows for more systematic and complex modeling of influencing factors.

Isik et al. (2009) utilized SEM in analyzing the impact of corporate strengths and weaknesses on project management competencies in construction projects. Doloi et al. (2012) used SEM in investigating factors affecting delays in construction projects.

Chen et al. (2012) explored the success variables (SVs) in construction partnering and the relationships among the SVs using SEM. Their research results showed that four successful factors (collaborative team culture, long-term quality perspective, consistent objectives, and resource sharing) had a significant influence on the success of construction partnering.

Lim et al. (2012) investigated the constituents and the constructs for predicting organizational flexibility by developing three mathematical models validated by SEM technique. According to the results of their models, the cost leadership initiative and supply chain capabilities of firms were the most important factors driving organizational flexibility.

Ramli et al. (2014) performed a study to construct a valid and reliable instrument to quantitative measure the level of conformance by construction practitioners towards building safety and health performance of low-cost housing in Malaysia. They proposed a model using SEM. Results indicated that architecture, building services, external environment, management approaches and maintenance management had a significant effect on the safety and health performance of low-cost housing in Malaysia.

Ye et al. (2015) studied the effects of market competition on the sustainability performance of the construction industry. A SEM approach was adopted and data from 30 provincial construction sectors in China were collected to test the proposed hypotheses. The results showed that market competition can influence industrial sustainability in three ways, namely (1) positive effects on the economic dimension, (2) negative effects on the environmental dimension, and (3) positive effects on the social dimension.

Qureshi and Kang (2015) studied organizational factors to assist project managers in handling organizational factors of project complexity in a more regulated fashion and developed a model using SEM technique. Their findings included the noticeable effect of project size on project complexity as well as positive effects of project variety and the interdependencies on project complexity.

As further examples of applications of SEM in construction industry, it can also be referred to the works of Lin et al. (2005); Wong and Cheung (2005); Jugdev et al. (2007); Stewart (2007); Isik (2007); Raymond and Bergeron (2008); Wong et al. (2008); Prasertrungruang and Hadikusumo (2009); Panuwatwanich et al. (2009); Wong et al. (2009); Eybpoosh (2010); Hung (2012); Al-Refaie (2013); Molwus et al. (2013); Bowen et al. (2014); Rajeh et al. (2015); Xiong et al. (2015); Wu et al. (2015).

8.9 Application of structural equation modeling to the current study

SEM was considered as the most appropriate and robust data analysis technique for achieving the objectives of the current thesis proposal. SEM takes a confirmatory approach in the analysis of the determinants (observable variables and latent dimensions) of safety performance in construction sites. First-order and second-order confirmatory factor analyses (CFA) will be employed to assess the reliability and validity of the factor structure of safety performance in construction sites.

SEM also enables multiple determinants of safety performance to be estimated simultaneously. Safety performance is a latent variable that cannot be directly observed and measured. Because SEM can reveal the interdependencies of observed variables and latent dimensions simultaneously, interdependencies of safety performance determinants can be fully modeled and tested. The relationships between determinants of safety performance will be analyzed by using SEM and a second-order factor analytical model, consisting of both measurement and structural models will be tested and validated by using SEM.

8.10 Software packages for structural equation modeling

Various structural equation modeling software packages are commercially available to support both first order and second order confirmatory factor analysis and path analysis required for testing hypothesized structural equation models such as IBM AMOS, LISREL, EQS, SAS CALIS, MPLUS, MX GRAPH, the RAMONA module of SYSTAT, and the SEPATH module of STATISTICA.

The syntax and output for each program is different. Demo versions of these software packages was tested. Comparing their observed analysis capabilities and popularity of use in the literature (Vieira 2011), LISREL was selected for this study to analyze structural equation models.

8.11 Brief information about LISREL

LISREL, an abbreviation of Linear Structural Relationships, is a computer program utilized in structural equation modeling (SEM). Although there are other statistical packages that can be used to analyze structural equation models, LISREL is generally considered as the most preferred statistical software. Structural equation models are often referred to as LISREL models. The SEM methodology is viewed by researchers as one of the most sophisticated statistical tools (Vieira 2011).

Each LISREL model is comprised of two sub-models: the measurement model and the structural model. While the measurement model shows how each latent variable is measured by its indicators, the structural model characterizes the associations between the variables, indicates the direction and statistical significance of each association, as well as the amount of variance in the endogenous variables explained by the respective proposed determinants. According to the literature (e.g. Anderson and Gerbing 1988), due to the complexity of some models and in order to achieve better results, the measurement and structural components should be analyzed separately, starting with the assessment of the measurement model, which includes content validity, unidimensionality, convergent validity, goodness of fit, reliability (internal consistency and composite reliability), discriminant validity testings, and then moving onto the estimation of the structural model.

8.12 Analysis of the proposed model by structural equation modeling (SEM)

In order to structure the causal relationship between the 16 latent dimensions with 168 observable variables were determined as being the key observable variables affecting the safety performance of construction sites as described in the previous chapters. This study hypothesized that 16 latent dimensions ("Scaffoldings and working platforms", "Ladders and stairs", "Working at height and protection against falling", "Lighting and electricity", "Housekeeping, order and tidiness", "Personal protective equipment (PPE)", "Fire prevention/protection", "Hand/power tools, machinery and devices", "Material handling (loading, transport, unloading, handling and storage)", "Traffic and transportation control", "First aid", "Excavation works", "Concrete and formwork", "Welding works", "Demolition works", and "Workers") predict "Safety performance of construction sites". The whole list of observable variables (with corresponding abbreviations) affecting safety performance of construction sites can be seen in Appendix C.

The data obtained from the 180 construction safety professionals were analyzed by using the SEM software package called LISREL Version 8.7.

In this part of the study, the choice of the type of the input matrix, estimation techniques, analysis approach, selection of goodness of fit indices, data screening, examination of univariate and multivariate normality, and sample size requirements were explained. Before moving on to the analysis of the measurement model, the following preliminary considerations were deemed pertinent.

8.12.1 Type of input matrix (correlation-covariance matrix)

Hair et al. (1998) defend that when the goal is to test a proposed theoretical framework, a covariance matrix should be used. According to Bentler et al. (2001), most of the statistical theory behind SEM have been developed on the assumption that the analysis applies to a covariance matrix. In addition, Baumgartner and Homburg (1996) recommends the utilization of covariance matrices in all analyses. Furthermore, a specific technical reason for approving the use of a covariance matrix is that, in general, when a correlation matrix is used, the results of chi-square test and standard errors are not correct (Bentler et al. 2001).

According to the suggestions and due to the abovementioned reasons, a covariance matrix was generated by using LISREL, and utilized as the input matrix in this study.

8.12.2 Estimation techniques with required sample size

Maximum likelihood (ML) is the default estimation method in most statistical packages and it is also the more widely used estimation method (Anderson and Gerbing 1988; Baumgartner and Homburg 1996; Bollen 1989; Diamantopoulos and Siguaw 2000). ML is quite consistent at producing efficient estimation and is rather robust against moderate violations of the normality assumption (Diamantopoulos and Siguaw 2000), provided that the sample comprises 100 or more observations (Anderson and Gerbing 1988; Steenkamp and van Trijp 1991).

Despite the existence of asymptotically distribution-free (ADF) methods, i.e., methods that make no assumptions on the distribution of the variables, ADF procedures are of little practical usefulness, implying the use of very large samples (Baumgartner and Homburg 1996; Diamantopoulos and Siguaw 2000; Steenkamp and van Trijp 1991). In addition, it is proven that ADF techniques does not necessarily yield better performances even when they are theoretically considered more appropriate (Baumgartner and Homburg 1996).

Weighted least squares (WLS), an example of an ADF method, as the estimation technique on an asymptotic covariance matrix, which can be calculated with PRELIS component of LISREL (Jöreskog and Sörbom 2002; Jöreskog et al. 2001) can be used. However, again, it is shown that WLS can be troublesome, regarding the chi-square test statistic, even with large samples (Diamantopoulos and Siguaw 2000). According to Steenkamp and van Trijp (1991), the utilization of WLS requires a sample as large as at least 1.5*(number of items)*(number of items + 1), which, in the case of the present study, will require a final sample with more than 42,500 observations (Number of items=168).

Comparisons of estimation methods shows maximum likelihood (ML) generally performs best, better than generalized least squares (GLS), and especially better than weighted least squares (WLS) (Ding et al. 1995; Olsson et al. 2000). ML is found to be relatively robust (e.g., to violations of the multivariate normality assumption) and is generally endorsed for most uses (Hu et al. 1999; Olsson et al. 2000; Iacobucci 2010).

Due to the abovementioned reasons and considering the sample size requirements, maximum likelihood (ML) was the selected as the estimation technique in this study.

8.12.3 Two-step analysis approach

In this study, conforming the Anderson and Gerbing’s (1988) two-step approach for structural equation modeling, the measurement model was analyzed separately and prior to the analysis of the structural model, This approach was selected for current analysis, due to its advantages, as compared to the single-step analysis, which, on the contrary, involved the simultaneous analysis of both measurement and structural models. Essentially, this approach allowed for unidimensionality assessments.

8.12.4 Goodness of fit indices

While there is no consensus on the appropriate index for assessing overall goodness- of-fit of a model (Ping 2004), the chi-square statistic is the most widely used fit index (Bagozzi and Heatherton 1994; Baumgartner and Homburg 1996; Ping 2004). The chi-square test measures the discrepancy between a hypothesized model and data (Bagozzi and Heatherton 1994), by testing “the null hypothesis that the estimated variance-covariance matrix deviates from the sample variance-covariance matrix only because of sampling error” (Baumgartner and Homburg 1996). Significant values of the chi-square test mean that there is a strong divergence between the data and the model. However, the chi-square goodness-of-fit test tends to inflate as the sample size increase, leads to the rejection of models with only slight divergences from the data, and limits its practical usefulness (Baumgartner and Homburg 1996). In this context, it is advised to report additional measures of fit (Bagozzi and Heatherton 1994; Baumgartner and Homburg 1996).

The following fit indices were chosen for this study, based on suggestions found in previous studies (Baumgartner and Homburg 1996; Ping 2004).

Four of these indices were absolute fit indices, assessing the overall model to data fit for structural and measurement models together (Bollen 1989; Hair et al. 1998): chi-square goodness-of-fit test (χ^2), ratio of χ^2 to degrees of freedom (χ^2/dof), root mean squared error of approximation (RMSEA), comparative fit index (CFI), and non-normed fit index (NNFI).

Relative Chi-Square (χ^2/dof): One common approach for mitigating the dependency of the $\chi2$ to the size of the sample data is to divide it by model's degrees of freedom (DOF). Various thresholds are suggested most of which are based on experiences and rules of thumb. The values less than 2 are considered as good fit indicators by Ullman (2006) and Ullman (2001). According to Jashapara (2003) and Kline (1998), ratios equal or less than 3 are considered as acceptable fit values. Authors such as Schumacker and Lomax (2004) take the upper limit as wide as 5 to address adequate model fit. Jackson et al. (2005) state that ratios less than 2 are indicators of well-fitted models, values less than 3 belong to acceptable fitted models, and values greater than 5 indicate that the model is definitely not acceptable.

Root Mean Error of Approximation (RMSEA): This index checks the average discrepancy between observed and predicted covariances. That is, it gives the absolute value for the covariance residuals. This index checks the lack of the model fit when compared to saturated or perfect model. Therefore, RMSEA is also a badness-of-fit index whose lower bound is zero. The lower the value of RMSEA, the lower differences among observed and hypothesized covariances, and hence, the better the model fit. Although RMSEA does not have an upper bound, there are various rules of thumb for its preferred values. For example, Jackson et al. (2005) consider values less than 0.05 as indicators of adequate fits. According to Byrne (2009), RMSEA is "one of the most informative criteria in covariance structure modeling". RMSEA values of less than 0.05 indicate a good fit, whereas values as high as 0.08 indicate a reasonable fit, represent reasonable errors of approximation in the population. Authors such as Chou and Bentler (1990), Bollen and Long (1992), and Brown and Cudeck (1993) mention that models with RMSEA values equal or less than 0.1 are good fitted models. Since there exists no upper bound for RMSEA, values slightly greater than these thresholds do not necessarily indicate poor fits. RMSEA is less affected by sample size, so RMSEA is an adequate measure for small samples (Jackson et al. 2005 and Garson 2008).

Comparative Fit Index (CFI): This index compares the hypothesized model with independence model in which no relationships exist among variables (model variables are uncorrelated), and checks the extent that the model fits the sample data better than the independent model. Reported CFI values range from 0 to 1, with values closer to 1 indicating better fit. CFI is adequate index for estimation of model fits even in small samples (Hu and Bentler 1999).

Normed Fit Index (NFI): This index is an alternative to CFI but it is more sensitive to sample size, so that, in small samples, it tends to under-estimate the model fit (Ullman 2001). Moreover, this index is not adequately capable to reflect model's parsimony since it may be over-estimated in complex models with higher number of parameters (Garson 2008). NFI is estimated through the Equation 8.1:

$$NFI = (\chi 2 \text{ for null model} - \chi 2 \text{ for hypothesized model}) / \chi 2 \text{ for null model} \quad \text{(Equation 8.1)}$$

Non-Normed Fit Index (NNFI): NNFI is the adjusted form of NFI for model complexity. It is also less sensitive to, or even independent of sample size (Marsh et al. 1988, and Marsh et al. 1996). Although its values may not range from 0 to 1, any reported value outside this range will be reset to 0 or 1 so as to values close to 1 reflect the perfect fit and 0 no fit. NNFI is estimated through the Equation 8.2:

$$NNFI = (\chi 2 \text{ for null model/DOFn} - \chi 2 \text{for hypothesized model/DOFh}) / (\chi 2 \text{ for null model/DOFn} - 1) \quad \text{(Equation 8.2)}$$

(Where DOF: degree of freedom, n: null model, h: hypothesized model)

Table 8.1 presented a description of these indices and recommended cut-offs.

Table 8.1: Descriptions and thresholds of goodness-of-fit indices used in the assessment of both measurement and structural models (Source: Bagozzi and Yi 1988; Baumgartner and Homburg 1996; Cote et al. 2001; Diamantopoulos and Siguaw 2000; MacCallum et al. 1996; Ping 2004)

Fit index	Description	Recommended Cut-offs
χ^2	Indicating the discrepancy between hypothesized model and data; Testing the null hypothesis that the estimated covariance–variance matrix deviating from the sample variance–covariance matrix only because of sampling error	p>0.05
χ^2 / dof	Because the chi-square test was sensitive to sample size and was only meaningful if the degrees of freedom were taken into account, its value was divided by the number of degrees of freedom	2–1 or 3–1
RMSEA	Showing how well the model fitted the population covariance matrix, taken the number of degrees of freedom into consideration	<0.05: good fit; <0.08: reasonable fit
NNFI	Showing how much better the model fitted, compared to a baseline model, normally the null model, adjusted for the degrees of freedom (could take values greater than one)	>0.90
CFI	Showing how much better the model fits, compared to a baseline model, normally the null model, adjusted for the degrees of freedom	>0.90

8.12.5 Data screening, examination of univariate and multivariate normality, and sample size requirements

8.12.5.1 Missing values

Before performing the data analysis, the data matrix (built in SPSS) should be checked for coding errors. If coding errors are detected, the original questionnaire is used to correct these errors (Baumgartner and Homburg 1996; Churchill 1999; Green et al. 1988). In this study, no coding errors were detected. Also, an inspection of the matrix was carried out with the objective of identifying extreme values that might pose some danger in terms of distorting influences, and no such values were found.

In addition, an investigation was made for missing values prior to data analysis. There are several ways to approach missing values, for example, substitution (e.g., case substitution and mean substitution), imputation (e.g., cold deck imputation, regression imputation, and multiple imputation), and model-based procedures (Hair et al. 1998). All methods for dealing with missing data contain advantages and disadvantages (Hair et al. 1998; Streiner 2002). The solutions offered in statistical packages as listwise and pairwise deletion, regression imputation, and expectation–maximization introduce bias in the analysis (Von Hippel 2004). Nevertheless, listwise case deletion is considered appropriate when the proportion of missing values is not too high (Hair et al. 1998). Since there were no missing values in this study, neither listwise deletion nor substitution was needed.

8.12.5.2 Normality assumption

In SEM, it is necessary to consider the issue of normality assumption. SEM is rather sensitive to the characteristics of the distribution of data, especially departures from multivariate normality. Severe violations of the normality assumption can be troublesome due to the possibility of inflating chi-square statistics, causing bias in critical values for determining coefficient significance, and affecting standard errors (Baumgartner and Homburg 1996; Hair et al. 1998; Steenkamp and van Trijp 1991). Also, one of the assumptions of the ML estimation technique is the normality of the variables (Cortina et al. 2001). Therefore, normality tests are conducted. PRELIS component of LISREL is used to conduct the tests of normality with reference to the values of skewness and kurtosis of the observed variables (Bollen 1989).

Before conducting the normality tests, it is necessary to define the variables in terms of level of measurement. In this study, all the observable variables were defined using a 5-point fuzzy Likert scale (Very low, low, medium, high, very high) then defuzzified into concrete numbers (crisp values). Likert scales correspond to ordinal scales, their output is widely treated at an interval level (Malhotra 1996). This occurs in the majority of investigations in social sciences and it is considered as an acceptable procedure (Kinnear and Taylor 1991). The reasonableness of this procedure is strengthened by the fact that the studied variables are indeed continuous and yet it is possible to measure them only as ordinal variables (Powers and Xie 2000). Similarly, in this study, numeric (crisp) values resulting from defuzzification of linguistic answers were treated as if they were obtained through metric scales.

8.12.5.3 Univariate normality

In order to examine of the univariate normality of the observable variables, the Skewness and Kurtosis indices reported by LISREL for each manifest variable should be tested. According to Kline (1998), absolute Skewness index values less than 3 and absolute Kurtosis index values less than 10 are considered acceptable for SEM models.

In this study, these criteria were met for all observable variables since the absolute Skewness values ranged from 0.004 for variable G6F9 to 2.577 for variable G1F2, and the absolute Kurtosis values ranged from 0.005 for variable G12F6 to 7.184 for variable G1F3. Skewness and Kurtosis values calculated for all observable variables were demonstrated in the below Table 8.2.

Table 8.2: Skewness and kurtosis values of observable variables

Univariate skewness and kurtosis statistics for observable variables					
Abbreviation of the variable	N	Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Std. Error
G1F1	180	-1,566	,181	2,011	,360
G1F2	180	**-2,577**	,181	6,944	,360
G1F3	180	-2,563	,181	**7,184**	,360
G1F4	180	-,479	,181	-,565	,360
G1F5	180	-1,236	,181	,944	,360
G1F6	180	-,834	,181	-,112	,360
G1F7	180	-,880	,181	-,284	,360
G1F8	180	-1,025	,181	,233	,360
G1F9	180	-,396	,181	-,722	,360
G1F10	180	-2,275	,181	5,120	,360
G1F11	180	-1,923	,181	3,923	,360
G1F12	180	-1,114	,181	,561	,360
G2F1	180	-1,047	,181	,189	,360
G2F2	180	-,982	,181	,161	,360
G2F3	180	-1,444	,181	1,334	,360
G2F4	180	-1,260	,181	,845	,360
G2F5	180	-,408	,181	-,993	,360
G2F6	180	-,766	,181	-,251	,360
G2F7	180	-,470	,181	-,725	,360
G2F8	180	,261	,181	-,890	,360
G2F9	180	-,828	,181	-,313	,360
G2F10	180	-,182	,181	-,827	,360
G3F1	180	-,815	,181	-,202	,360
G3F2	180	-1,325	,181	1,168	,360
G3F3	180	-,863	,181	,185	,360
G3F4	180	-,981	,181	,258	,360
G3F5	180	-,893	,181	-,283	,360
G3F6	180	-,994	,181	,071	,360
G3F7	180	-1,193	,181	,741	,360
G3F8	180	-,851	,181	-,092	,360
G3F9	180	-1,153	,181	,521	,360
G4F1	180	-,622	,181	-,544	,360
G4F2	180	-,496	,181	-,905	,360
G4F3	180	-1,958	,181	3,552	,360

Table 8.2: Skewness and kurtosis values of observable variables (Cont'd)

Univariate skewness and kurtosis statistics for observable variables					
Abbreviation of the variable	N	Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Std. Error
G4F4	180	-1,442	,181	1,400	,360
G4F5	180	-,787	,181	-,458	,360
G4F6	180	-1,082	,181	-,021	,360
G4F7	180	-1,230	,181	,962	,360
G4F8	180	-1,399	,181	1,280	,360
G4F9	180	-,573	,181	-,550	,360
G4F10	180	-1,144	,181	,573	,360
G5F1	180	-,030	,181	-,726	,360
G5F2	180	,273	,181	-,725	,360
G5F3	180	,267	,181	-,975	,360
G5F4	180	-,643	,181	-,350	,360
G5F5	180	-,657	,181	-,663	,360
G5F6	180	-,649	,181	-,280	,360
G5F7	180	-,478	,181	-,792	,360
G5F8	180	,017	,181	-1,120	,360
G5F9	180	,309	,181	-1,118	,360
G5F10	180	,028	,181	-,997	,360
G5F11	180	-,286	,181	-,892	,360
G5F12	180	-,094	,181	-1,061	,360
G6F1	180	-,580	,181	-,758	,360
G6F2	180	-,161	,181	-1,045	,360
G6F3	180	-,619	,181	-,697	,360
G6F4	180	-1,005	,181	,244	,360
G6F5	180	-,414	,181	-,739	,360
G6F6	180	-1,248	,181	,944	,360
G6F7	180	-,742	,181	-,406	,360
G6F8	180	-,294	,181	-1,042	,360
G6F9	180	,004	,181	-1,127	,360
G7F1	180	-,878	,181	,009	,360
G7F2	180	-,762	,181	-,307	,360
G7F3	180	-,598	,181	-,613	,360
G7F4	180	-,711	,181	-,527	,360
G7F5	180	-,769	,181	-,563	,360
G7F6	180	-,333	,181	-,910	,360

Table 8.2: Skewness and kurtosis values of observable variables (Cont'd)

Univariate skewness and kurtosis statistics for observable variables					
Abbreviation of the variable	N	Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Std. Error
G7F7	180	-,704	,181	-,644	,360
G7F8	180	-,567	,181	-,807	,360
G7F9	180	-,660	,181	-,516	,360
G7F10	180	-,356	,181	-,801	,360
G8F1	180	-,728	,181	-,494	,360
G8F2	180	-1,042	,181	,426	,360
G8F3	180	-1,054	,181	,226	,360
G8F4	180	-1,100	,181	,021	,360
G8F5	180	-1,305	,181	,923	,360
G8F6	180	-,862	,181	-,120	,360
G8F7	180	-,652	,181	-,421	,360
G8F8	180	-,478	,181	-,795	,360
G8F9	180	-,190	,181	-1,017	,360
G8F10	180	-,244	,181	-,952	,360
G8F11	180	-,823	,181	-,189	,360
G8F12	180	-,815	,181	-,456	,360
G9F1	180	-,459	,181	-,871	,360
G9F2	180	-1,176	,181	,510	,360
G9F3	180	-1,038	,181	,181	,360
G9F4	180	-1,004	,181	-,045	,360
G9F5	180	-,845	,181	-,422	,360
G9F6	180	-,421	,181	-,785	,360
G9F7	180	-1,256	,181	,490	,360
G9F8	180	-,828	,181	-,614	,360
G9F9	180	-,933	,181	-,337	,360
G9F10	180	-,552	,181	-,865	,360
G9F11	180	-,485	,181	-,834	,360
G9F12	180	-1,047	,181	,189	,360
G10F1	180	-,821	,181	-,163	,360
G10F2	180	-,673	,181	-,452	,360
G10F3	180	-1,422	,181	1,352	,360
G10F4	180	-1,168	,181	,525	,360
G10F5	180	-,257	,181	-,868	,360
G10F6	180	-,221	,181	-,904	,360
G10F7	180	-,350	,181	-,860	,360

Table 8.2: Skewness and kurtosis values of observable variables (Cont'd)

Univariate skewness and kurtosis statistics for observable variables					
Abbreviation of the variable	N	Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Std. Error
G10F8	180	-,534	,181	-,767	,360
G10F9	180	-,414	,181	-,834	,360
G10F10	180	-1,526	,181	1,305	,360
G10F11	180	-,443	,181	-,850	,360
G10F12	180	-,869	,181	-,204	,360
G11F1	180	-,299	,181	-,898	,360
G11F2	180	-,085	,181	-,860	,360
G11F3	180	-,197	,181	-,991	,360
G11F4	180	-,240	,181	-1,002	,360
G11F5	180	-,247	,181	-1,123	,360
G11F6	180	-,128	,181	-1,100	,360
G11F7	180	-,131	,181	-1,002	,360
G11F8	180	-,275	,181	-1,082	,360
G12F1	180	-1,049	,181	-,178	,360
G12F2	180	-1,839	,181	3,462	,360
G12F3	180	-1,145	,181	,561	,360
G12F4	180	-1,271	,181	,908	,360
G12F5	180	-,846	,181	-,249	,360
G12F6	180	-,978	,181	-,005	,360
G12F7	180	-,852	,181	-,277	,360
G12F8	180	-1,687	,181	2,132	,360
G12F9	180	-1,666	,181	2,397	,360
G12F10	180	-1,278	,181	,814	,360
G12F11	180	-,704	,181	-,731	,360
G12F12	180	-,788	,181	-,488	,360
G13F1	180	-,965	,181	-,147	,360
G13F2	180	-1,641	,181	2,067	,360
G13F3	180	-1,562	,181	1,590	,360
G13F4	180	-1,115	,181	,297	,360
G13F5	180	-,819	,181	-,289	,360
G13F6	180	-,654	,181	-,733	,360
G13F7	180	-,931	,181	-,225	,360
G13F8	180	-,843	,181	-,337	,360
G13F9	180	-1,484	,181	1,400	,360

Table 8.2: Skewness and kurtosis values of observable variables (Cont'd)

Univariate skewness and kurtosis statistics for observable variables					
Abbreviation of the variable	N	Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Std. Error
G13F10	180	-1,391	,181	1,269	,360
G13F11	180	-,917	,181	-,167	,360
G14F1	180	-,533	,181	-,744	,360
G14F2	180	-,863	,181	-,106	,360
G14F3	180	-1,595	,181	2,423	,360
G14F4	180	-,743	,181	-,211	,360
G14F5	180	-1,593	,181	2,332	,360
G14F6	180	-1,154	,181	,583	,360
G14F7	180	-1,885	,181	3,458	,360
G14F8	180	-1,360	,181	1,051	,360
G14F9	180	-1,000	,181	-,017	,360
G14F10	180	-1,161	,181	,469	,360
G15F1	180	-1,241	,181	,877	,360
G15F2	180	-1,056	,181	,184	,360
G15F3	180	-1,599	,181	1,854	,360
G15F4	180	-1,356	,181	,976	,360
G15F5	180	-1,109	,181	,188	,360
G15F6	180	-,276	,181	-,920	,360
G15F7	180	-,518	,181	-,591	,360
G15F8	180	-1,332	,181	1,032	,360
G15F9	180	-1,034	,181	,071	,360
G16F1	180	-1,412	,181	1,376	,360
G16F2	180	-1,251	,181	,651	,360
G16F3	180	-1,681	,181	2,288	,360
G16F4	180	-1,417	,181	1,206	,360
G16F5	180	-1,700	,181	2,182	,360
G16F6	180	-,624	,181	-,609	,360
G16F7	180	-,883	,181	-,269	,360
G16F8	180	-1,591	,181	1,427	,360
G16F9	180	-,662	,181	-,614	,360
G16F10	180	-1,225	,181	,794	,360
Valid N (listwise)	180				

8.12.5.4 Multivariate normality

In this study, all observable variables did not reveal significant kurtosis and skewness as mentioned in univariate normality tests, which did not suggest a potential departure from normality. However, according to Hair et al. (1998), large sample sizes tend to mitigate violations of the normality assumption caused by excessive kurtosis—which is more problematic than skewness, according to Bollen (1989), namely by reducing biases in parameter estimates.

In addition, also as already mentioned, the adopted estimation technique, ML, is robust against several types of the violation of the multivariate normality assumption (Bollen 1989). Additionally, the ML estimator shows a superior performance in terms of bias in parameter estimates (Cortina et al. 2001). Moreover, according to Barnes et al. (2001), variables are rarely normally distributed. In fact, the distribution of variables measured on Likert scales are often skewed toward one end of the scale (Barnes et al. 2001). Barnes et al. (2001) suggest that, for practical purposes, the distributions of the sample variables are not wildly non-normal. ML can be used, since, its results are probably reliable in most situations.

Furthermore, the measure of relative multivariate kurtosis, printed by the PRELIS program (Jöreskog and Sörbom 2002) was 1.019 as demonstrated in Table 8.3 below. This relative multivariate kurtosis value 1.019 was considered as relatively small and satisfying the suggested limits, therefore, along with the variables showing univariate normality, the multivariate distribution was reasonably normal, similarly to what was concluded in previous analyses (e.g., Benson and Bandalos 1992).

Table 8.3: Calculated relative multivariate kurtosis output (By LISREL)

Test of Multivariate Normality for Continuous Variables							
Skewness			Kurtosis			Skewness and Kurtosis	
Value	Z-Score	P-Value	Value	Z-Score	P-Value	Chi-Square	P-Value
28223.262	32.750	0.000	29109.028	13.521	0.000	1255.372	0.000
Relative Multivariate Kurtosis = 1.019							

8.12.5.5 Sample size

In this part, the question of sample size, "How many observations are necessary to have a good SEM model?" was examined. Sample size should be sufficiently large. If the variables are reliable and the effects are strong and the model is not overly complex, smaller samples will suffice (Bearden et al. 1982; Bollen 1990).

Although there is no fixed rule, Crowley and Fan (1997) proposed a number of 200; Jayaram et al. (2004) suggested a number of 150 as the minimum sample size. According to Crowley and Fan (1997) and Bentler and Chou (1987), taking into account of the model complexity and number of parameters to be estimated, each estimated parameter should have 5 to 10 participants to support.

Nunnally (1967) suggested that in SEM estimation 'a good rule was to have at least 10 times as many subjects as variables. Tanaka (1987) argued that sample size should be dependent on the number of estimated parameters (the latent variables and their correlations) rather than on the total number of indicators. Bentler (1989) suggested a 5:1 ratio of sample size to number of free parameters. Boomsma (1982) suggested using a ratio r=p/k (where r: ratio of indicators to latent variables, p:number of indicator variables, k: number of latent variables) and his simulations resulted for r=2 would require a sample size of at least 400 and for r=4 would require a sample size of at least 100 for adequate analysis; and, Marsh et al (1988), Marsh et al (1996), Marsh et al (1998) ran 35,000 Monte

Carlo simulations on LISREL CFA analysis, yielding data suggested that: r=2 would require a sample size of at least 400; r=3 would require a sample size of at least 200; r=12 would require a sample size of at least 50 (Westland 2010). In this study, the calculated ratio of indicators to latent dimensions r=168/17≈10 requiring a sample size of at least 50 observations.

SEM models can perform well even with small samples 50 to 100. If the measurement is strong (3 or 4 indicators per factor, and good reliabilities), and the structural path model is not overly complex, then samples of size 50 or 100 can be plenty (Iacobucci 2010). In terms of bias reduction and even just getting the model to run, with "three or more indicators per factor, a sample size of 100 will usually be sufficient for convergence," and a sample size of 150 "will usually be sufficient for a convergent and proper solution" (Anderson and Gerbing 1984).

In this study, 180 full&valid responses satisfied the sample size requirements explained above in detail. After introducing the descriptive statistics and describing the analysis of the proposed model by structural equation modeling, the assessment of the measurement model by SEM will be explained in the following part.

8.13 Assessment of measurement model

8.13.1 Introduction

In this part, the assessment of the measurement model by SEM will be presented inclusive of content validity, unidimensionality, convergent validity, goodness of fit, reliability (internal consistency and composite reliability), and discriminant validity testings. Analysis of the measurement model will be carried out using factor analysis by first-order and second-order confirmatory factor analysis (CFA) for the assessment of unidimensionality, convergent validity, reliability, and discriminant validity.

8.13.2 Validity of the safety performance measurement model

Testing the construct validity of safety performance measurement variables provides the degree to which a latent variable measures what it intends to measure. Construct validity testing is comprised of numerous sub-dimensions, all of which must be satisfied to achieve construct validity. These sub-dimensions include: "content validity", "unidimensionality", "convergent validity", "scale reliability", and "discriminant validity".

8.13.2.1 Content validity testing of safety performance measures

Content validity is testing the rate of extent to which a constituent variable belongs to its corresponding construct. Since content validity cannot be tested by using statistical tools, an in-depth literature survey is necessary to keep the researcher's judgement on the right track (Dunn et al. 1994).

In this study, an extensive literature review was conducted to specify the observable variables that define latent dimensions. In addition to an in-depth literature review, face-to-face interviews with construction safety professionals were conducted to assure the validity of the constituents of the latent dimensions. At the end of the interviews, observable variables were collected together (Appendix C), and the content validity was achieved. A 16-dimensional construct was proposed in this study to measure "Safety Performance of Construction Sites" (Latent dimensions were "Scaffoldings and working platforms", "Ladders and stairs", "Working at height and protection against falling", "Lighting and electricity", "Housekeeping, order and tidiness", "Personal protective equipment (PPE)", "Fire prevention/protection", "Hand/power tools, machinery and devices", "Material handling (loading, transport, unloading, handling and storage)", "Traffic and transportation control", "First aid", "Excavation works", "Concrete and formwork", "Welding works", "Demolition works", and "Workers").

Empirical validity tests such as unidimensionality, convergent validity, goodness of fit, reliability (internal consistency and composite reliability), and discriminant validity will follow content validity.

8.13.2.2 Unidimensionality Test for "Safety performance of construction sites"

Achieving unidimensional measurement is a crucial undertaking in theory testing and development. A necessary condition for assigning meaning to estimated constructs is that the measures that are posited as alternate indicators of each construct should be acceptably unidimensional (Anderson and Gerbing 1988).

According to Byrne (2001), the fit statistics resulting from the model will be equivalent, either if it is parameterized as a first-order or a second-order structure. The second-order model is equivalent to the first-order model, only the second-order structure is a special case of the first-order structure, an alternative account of the association between the first-order factors (Byrne 2001; Kline 2005). The decision on whether to model a certain measurement instrument as first or second-order structure relies ultimately on what theory suggests (Byrne 2001; Garver and Mentzer 1999). Exploratory factor analysis is not able to test models with higher-order factors (Hunter and Gerbing 1982; Rubio et al. 2001), but this can be done through confirmatory factor analysis using SEM.

The object of analysis is to find whether unidimensionality is held for each of the first-order factors or dimensions (Steenkamp and van Trijp 1991). In this study, a second-order CFA using SEM was performed on the observable variables affecting "Safety performance of construction sites", aiming to find out whether there is support for the second-order factor structure, and for the unidimensionality of each of the 16 first-order constructs.

First of all, in order to execute a second-order CFA, a covariance matrix was generated using PRELIS component of LISREL.

As previously mentioned, a possible evidence of potential threats to unidimensionality is the number of absolute values above 3 in the matrix of standardized residuals, which may indicate that the model does not satisfactorily estimate the relationship between a given pair of variables. The 'standard' cut-off is a standardized residual above 3, corresponding to a p-value<0.01 (Jöreskog and Sörbom 1993).

Also, modification indices above 5 may also be another sign of potential threats to unidimensionality (Anderson and Gerbing 1988; Gefen 2003). If the event that the LISREL output suggests potential dimensionality problems, unidimensionality can be improved by tackling the most problematic pairs of items, being the addition of error covariances between items the most commonly used way of improving the model fit (Baumgartner and Homburg 1996; Diamantopoulos and Siguaw 2000; Ping 2004).

In this study, the number of absolute standard residuals above 3 was calculated as 673 by LISREL representing 4.77% < 6% of the total of pairs of the matrix of standard residuals and the number of modification indices above 5 was calculated as 613 by LISREL representing 4.34% < 6% of the total of pairs of the matrix of modification indices as demonstrated in Table 8.4 below, satisfying the suggested cut-offs (6%) by Vieira (2011).

Table 8.4: Summary Statistics for Standardized Residuals and Modification Indices by LISREL

Summary Statistics for Standardized Residuals and Modification Indices
Smallest Standardized Residual = -5.41
Largest Standardized Residual = 7.49
of Absolute Standardized Residual >3 = 673
of Modification Indices >5 = 613

Unidimensionality is a crucial and necessary (but not sufficient) condition for construct validity (Anderson and Gerbing 1988), therefore, the following parts address the issues of convergent and discriminant validity, as well as reliability.

8.13.2.3 Convergent Validity Tests for "Safety Performance"

Convergent validity is the extent to which the latent variable correlates to corresponding items designed to measure the same latent variable. Convergent validity tests if all the items measure a latent variable cluster together and form a single latent variable.

Examination of first-order factor loadings, examination of second-order factor loadings, and examination of overall goodness of fit (including both first-order and second-order factor structures) will be utilized in this study to examine convergent validity.

8.13.2.3.1 Examination of first-order factor loadings

In first-order models, convergent validity is supported if each observable variable loads significantly onto the latent variable that they are purported to measure (Anderson and Gerbing 1988; Hair et al. 1998; Steenkamp and van Trijp 1991). The evidence of convergent validity is reinforced by the substantial loadings (greater than 0.50) for all items (Hildebrandt 1987; Steenkamp and van Trijp 1991). Hair et al. (2010) recommends that standardized factor loading should be greater than 0.50. In this study, the factor loadings calculated by LISREL for all 168 observable variables were greater than 0.50, consequently supporting the convergent validity (12 for G1, 10 for G2, 9 for G3, 10 for G4, 12 for G5, 9 for G6, 10 for G7, 12 for G8, 12 for G9, 12 for G10, 8 for G11, 12 for G12, 11 for G13, 10 for G14, 19 for G15, and 10 for G16). Factor loadings of the observable variables of latent dimensions were presented in Tables 8.5.

Table 8.5: Factor loadings of the observable variables of latent dimensions

Factor loadings of the observable variables							
G1F1	0,70	G5F2	0,69	G9F1	0,72	G12F11	0,78
G1F2	0,66	G5F3	0,73	G9F2	0,79	G12F12	0,75
G1F3	0,69	G5F4	0,75	G9F3	0,79	G13F1	0,79
G1F4	0,58	G5F5	0,74	G9F4	0,79	G13F2	0,79
G1F5	0,71	G5F6	0,67	G9F5	0,77	G13F3	0,82
G1F6	0,66	G5F7	0,75	G9F6	0,80	G13F4	0,79
G1F7	0,64	G5F8	0,80	G9F7	0,75	G13F5	0,67
G1F8	0,65	G5F9	0,70	G9F8	0,76	G13F6	0,77
G1F9	0,64	G5F10	0,72	G9F9	0,81	G13F7	0,83
G1F10	0,57	G5F11	0,76	G9F10	0,79	G13F8	0,81
G1F11	0,68	G5F12	0,75	G9F11	0,75	G13F9	0,79
G1F12	0,61	G6F1	0,81	G9F12	0,74	G13F10	0,82
G2F1	0,67	G6F2	0,78	G10F1	0,76	G13F11	0,77
G2F2	0,75	G6F3	0,78	G10F2	0,57	G14F1	0,79
G2F3	0,71	G6F4	0,76	G10F3	0,65	G14F2	0,80
G2F4	0,67	G6F5	0,82	G10F4	0,65	G14F3	0,74
G2F5	0,70	G6F6	0,73	G10F5	0,63	G14F4	0,70
G2F6	0,78	G6F7	0,80	G10F6	0,68	G14F5	0,75
G2F7	0,80	G6F8	0,84	G10F7	0,82	G14F6	0,66
G2F8	0,63	G6F9	0,71	G10F8	0,79	G14F7	0,77
G2F9	0,67	G7F1	0,68	G10F9	0,81	G14F8	0,76
G2F10	0,56	G7F2	0,70	G10F10	0,55	G14F9	0,85
G3F1	0,60	G7F3	0,78	G10F11	0,73	G14F10	0,79
G3F2	0,54	G7F4	0,84	G10F12	0,77	G15F1	0,73
G3F3	0,61	G7F5	0,77	G11F1	0,79	G15F2	0,81
G3F4	0,76	G7F6	0,83	G11F2	0,81	G15F3	0,71
G3F5	0,69	G7F7	0,77	G11F3	0,93	G15F4	0,78
G3F6	0,64	G7F8	0,83	G11F4	0,95	G15F5	0,72
G3F7	0,68	G7F9	0,81	G11F5	0,91	G15F6	0,60
G3F8	0,74	G7F10	0,67	G11F6	0,86	G15F7	0,65
G3F9	0,73	G8F1	0,75	G11F7	0,80	G15F8	0,62
G4F1	0,57	G8F2	0,79	G11F8	0,65	G15F9	0,74
G4F2	0,64	G8F3	0,76	G12F1	0,83	G16F1	0,70
G4F3	0,69	G8F4	0,82	G12F2	0,69	G16F2	0,79
G4F4	0,69	G8F5	0,78	G12F3	0,76	G16F3	0,80
G4F5	0,79	G8F6	0,76	G12F4	0,80	G16F4	0,76
G4F6	0,73	G8F7	0,78	G12F5	0,84	G16F5	0,79
G4F7	0,72	G8F8	0,79	G12F6	0,73	G16F6	0,65
G4F8	0,75	G8F9	0,77	G12F7	0,78	G16F7	0,76
G4F9	0,74	G8F10	0,73	G12F8	0,63	G16F8	0,60
G4F10	0,72	G8F11	0,79	G12F9	0,74	G16F9	0,61
G5F1	0,72	G8F12	0,78	G12F10	0,64	G16F10	0,74

8.13.2.3.2 Examination of second-order factor loadings

In second-order CFA, an additional requirement should be accomplished for assessing convergent validity: the relationships between the first-order factors and the second-order factor should be significant (Benson and Bandalos 1992). This was also satisfied for the second-order model in this study, the calculated minimum standardized factor loading by LISREL was for G11=0.65 greater than recommended value 0.5 ((Hildebrandt 1987; Steenkamp and van Trijp 1991; Hair et al. 2010), suggesting that there was sufficient evidence of convergent validity. The standardized factor loadings of the second-order latent factor "Safety Performance of Construction Sites" was demonstrated in Table 8.6 below.

Table 8.6: Standardized factor loadings of the second-order latent factor SP: "Safety Performance of Construction Sites"

Second-order Factor	**Latent Dimensions**	**Standardized Loadings**
Safety Performance of Construction Sites (SP)	G1	0,79
	G2	0,83
	G3	0,88
	G4	0,91
	G5	0,85
	G6	0,85
	G7	0,83
	G8	0,90
	G9	0,94
	G10	0,94
	G11	0,65
	G12	0,93
	G13	0,88
	G14	0,94
	G15	0,93
	G16	0,86

8.13.2.3.3 Assessment of overall goodness of fit (first-order latent dimensions)

The evidence of convergent validity is further strengthened by the good overall fit of the model (Steenkamp and van Trijp 1991). The overall fit of the model is assessed by examination of goodness-of-fit indices.

In this study, the calculated first-order model fit statistics in LISREL, were within the generally accepted thresholds, and satisfied the recommendations.

<u>For Latent Dimension G1:</u> Although the Chi-square test was significant (χ^2 = 78,32, p = 0.0037), the ratio chi-square/degrees of freedom was below 2 (dof = 48, χ^2 /dof = 1.63)—normally a ratio in the range of 2–1 (Hair et al. 1998) or 3–1 (Kline 1998; Jashapara 2003; Cote et al. 2001), was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.98), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.059) were indicating good fit (Diamantopoulos and Siguaw 2000; MacCallum et al. 1996; Bentler, 1989). As presented in Table 8.7, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.7: Fit indices for latent dimension G1

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G1
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,98
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,059
$\chi2$/dof	< 3	1,63

For Latent Dimension G2: Although the Chi-square test was significant (χ^2 = 37,06, p = 0.0043), the ratio chi-square/degrees of freedom was below 2 (dof = 24, χ^2 /dof = 1.54) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.99), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.055) were indicating good fit. As presented in Table 8.8, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.8: Fit indices for latent dimension G2

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G2
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,055
$\chi 2$/dof	< 3	1,54

For Latent Dimension G3: The Chi-square test was not significant (χ^2 = 33,95, p = 0.066>0.05), the ratio chi-square/degrees of freedom was below 2 (dof = 23, χ^2 /dof = 1.48) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.99), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.052) were indicating good fit. As presented in Table 8.9, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.9: Fit indices for latent dimension G3

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G3
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,052
$\chi 2$/dof	< 3	1,48

<u>For Latent Dimension G4:</u> The Chi-square test was not significant (χ^2 = 38,28, p = 0.07353>0.05), the ratio chi-square/degrees of freedom was below 2 (dof = 27, χ^2 /dof = 1.42) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.99), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.048) were indicating good fit. As presented in Table 8.10, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.10: Fit indices for latent dimension G4

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G4
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,048
$\chi 2$/dof	< 3	1,42

<u>For Latent Dimension G5:</u> Although the Chi-square test was significant (χ^2 = 65,27, p = 0.040), the ratio chi-square/degrees of freedom was below 2 (dof = 45,

χ^2 /dof = 1.39) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.99), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.047) were indicating good fit. As presented in Table 8.11, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.11: Fit indices for latent dimension G5

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G5
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,047
$\chi 2$/dof	< 3	1,39

For Latent Dimension G6: Although the Chi-square test was significant (χ^2 = 36,71, p = 0.047), the ratio chi-square/degrees of freedom was below 2 (dof = 24, χ^2 /dof = 1.53) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.99), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.054) were indicating good fit. As presented in Table 8.12, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.12: Fit indices for latent dimension G6

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G6
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,054
$\chi 2$/dof	< 3	1,53

<u>For Latent Dimension G7:</u> The Chi-square test was not significant (χ^2 = 30,79, p = 0.077>0,05), the ratio chi-square/degrees of freedom was below 2 (dof = 21, χ^2 /dof = 1.47) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.99), and the comparative fit index (CFI = 1.00), as well as the root mean square error of approximation (RMSEA = 0.051) were indicating good fit. As presented in Table 8.13, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.13: Fit indices for latent dimension G7

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G7
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	1,00
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,051
$\chi 2$/dof	< 3	1,47

<u>For Latent Dimension G8:</u> Although the Chi-square test was significant (χ^2 = 57,61, p = 0.0094), the ratio chi-square/degrees of freedom was below 2 (dof =

35, χ^2 /dof = 1.65) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.99), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.060) were indicating good fit. As presented in Table 8.14, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.14: Fit indices for latent dimension G8

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G8
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,060
$\chi2$/dof	< 3	1,65

For Latent Dimension G9: Although the Chi-square test was significant (χ^2 = 79,80, p = 0.00019), the ratio chi-square/degrees of freedom was below 2 (dof = 40, χ^2 /dof = 2.00) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.98), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.075) were indicating good fit. As presented in Table 8.15, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.15: Fit indices for latent dimension G9

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G9
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,98
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,075
$\chi 2$/dof	< 3	2,00

For Latent Dimension G10: Although the Chi-square test was significant (χ^2 = 63,23, p = 0.014), the ratio chi-square/degrees of freedom was below 2 (dof = 41, χ^2 /dof = 1,54) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.99), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.055) were indicating good fit. As presented in Table 8.16, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.16: Fit indices for latent dimension G10

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G10
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,055
$\chi 2$/dof	< 3	1,54

For Latent Dimension G11: The Chi-square test was not significant (χ^2 = 23,83, p = 0.10>0.05), the ratio chi-square/degrees of freedom was below 2 (dof = 16, χ^2

/dof = 1,47) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.99), and the comparative fit index (CFI = 1.00), as well as the root mean square error of approximation (RMSEA = 0.051) were indicating good fit. As presented in Table 8.17, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.17: Fit indices for latent dimension G11

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G11
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	1,00
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,055
$\chi2$/dof	< 3	1,47

For Latent Dimension G12: Although the Chi-square test was significant (χ^2 = 98,04, p = 0.00), the ratio chi-square/degrees of freedom was below 3 (dof = 48, χ^2 /dof = 2,04) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.98), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.076) were indicating good fit. As presented in Table 8.18, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.18: Fit indices for latent dimension G12

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G12
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,98
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,076
$\chi2$/dof	< 3	2,04

<u>For Latent Dimension G13:</u> Although the Chi-square test was significant (χ^2 = 56,33, p = 0.013), the ratio chi-square/degrees of freedom was below 2 (dof = 35, χ^2 /dof = 1,61) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.99), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.058) were indicating good fit. As presented in Table 8.19, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the ecommendations.

Table 8.19: Fit indices for latent dimension G13

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G13
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,058
$\chi2$/dof	< 3	1,61

<u>For Latent Dimension G14:</u> Although the Chi-square test was significant (χ^2 = 43,98, p = 0.037), the ratio chi-square/degrees of freedom was below 2 (dof = 29,

χ^2 /dof = 1,52) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.99), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.054) were indicating good fit. As presented in Table 8.20, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.20: Fit indices for latent dimension G14

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G14
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,054
$\chi2$/dof	< 3	1,52

<u>For Latent Dimension G15:</u> Although the Chi-square test was significant (χ^2 = 37,55, p = 0.015), the ratio chi-square/degrees of freedom was below 2 (dof = 21, χ^2 /dof = 1,79) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.98), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.066) were indicating good fit. As presented in Table 8.21, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.21: Fit indices for latent dimension G15

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G15
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,98
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,066
$\chi 2$/dof	< 3	1,79

For Latent Dimension G16: Although the Chi-square test was significant (χ^2 = 48,73, p = 0.022), the ratio chi-square/degrees of freedom was below 2 (dof = 31, χ^2 /dof = 1,57) was indicative of a good and acceptable fit. The non-normed fit index (NNFI = 0.98), and the comparative fit index (CFI = 0.99), as well as the root mean square error of approximation (RMSEA = 0.057) were indicating good fit. As presented in Table 8.22, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.22: Fit indices for latent dimension G16

Fit indices for the proposed safety performance model	Recommended value	Latent Dimension: G16
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,98
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,057
$\chi 2$/dof	< 3	1,57

All of the first-order measurement latent dimensions showed a good fit to the data. All of the first-order measurement fit statistics (χ^2 /dof, NNFI, CFI and

RMSEA) calculated by LISREL were within the generally accepted thresholds and satisfied the recommendations. Fit indices for all of the first-order measurement latent dimensions were listed in Table 8.23.

Table 8.23: Fit indices for the first-order measurement latent dimensions

Fit indices for the proposed safety performance model	Recommended value	Latent dimensions affecting safety performance at construction sites							
		G1	G2	G3	G4	G5	G6	G7	G8
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,98	0,99	0,99	0,99	0,99	0,99	0,99	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99	0,99	0,99	0,99	0,99	0,99	1,00	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,059	0,055	0,052	0,048	0,047	0,054	0,051	0,06
$\chi 2$/dof	< 3	1,63	1,54	1,48	1,42	1,39	1,53	1,47	1,65

Table 8.23: Fit indices for the first-order measurement latent dimensions (Cont'd)

Fit indices for the proposed safety performance model	Recommended value	Latent dimensions affecting safety performance at construction sites							
		G9	G10	G11	G12	G13	G14	G15	G16
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,98	0,99	0,99	0,98	0,99	0,99	0,98	0,99
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,99	0,99	1,00	0,99	0,99	0,99	0,99	0,99
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,075	0,055	0,051	0,076	0,058	0,054	0,066	0,057
$\chi 2$/dof	< 3	2,00	1,54	1,47	2,04	1,61	1,52	1,79	1,57

8.13.2.4 Reliability Tests for Safety Performance

Reliability is examined after assessing unidimensionality and convergent validity, given that a construct can exhibit an acceptable reliability even if it does not meet the convergent validity criteria (Steenkamp and van Trijp 1991).

The scale reliability is the internal consistency of a latent variable and is measured most commonly with a coefficient called “Cronbach’s alpha”. The purpose of testing the reliability of a construct is to understand how each observed indicator represents its correspondent latent variable.

Cronbach’s alpha should be assessed only after unidimensionality is proven (Anderson and Gerbing 1988), namely because, as Hunter and Gerbing (1982) stated that, “Cronbach’s alpha provides an unbiased estimate of the reliability of the cluster score only if the scale is unidimensional”. Also, as Hulin et al. (2001) stated that, it is possible for a number of items to be interrelated (i.e., show internal consistency) and still not being homogeneous (i.e. not being unidimensional).

According to the reliability analysis results performed by using SPSS, latent variables, their abbreviations and Cronbach’s alpha values were shown in Table 8.24. The lowest Cronbach’s alpha was calculated as 0,879 for latent dimension “G3: Working at Height and Protection against Falling”. Cronbach’s alpha values for the first-order constructs were all greater than this value (0,879). The proposed second-order construct of “Safety performance of construction sites” should also be considered and its Cronbach’s alpha was calculated as 0.992. These reliability values were quite satisfactory since the Cronbach’s alpha coefficients were all above 0.70, the minimum value recommended by Nunnally (1978), Nunnally and Bernstein (1994) and Hair et al. (2006), suggesting adequate reliability.

Table 8.24: Cronbach's alpha coefficients of the latent variables

Latent Variables	Abbreviation	Cronbach's alpha values (Internal consistency)
SAFETY PERFORMANCE	SP	0,992
1) Scaffoldings and Working Platforms	G1	0,893
2) Ladders and Stairs	G2	0,906
3) Working at Height and Protection Against Falling	G3	0,879
4) Lighting and Electricity	G4	0,907
5) Housekeeping, Order and Tidiness	G5	0,932
6) Personal Protective Equipment (PPE)	G6	0,934
7) Fire Prevention/Protection	G7	0,937
8) Hand/Power Tools, Machinery and Devices	G8	0,947
9) Material Handling (Loading, Transport, Unloading, Handling and Storage)	G9	0,947
10)Traffic and Transportation Control	G10	0,923
11) First Aid	G11	0,952
12) Excavation Works	G12	0,937
13) Concrete and Formwork	G13	0,945
14) Welding Works	G14	0,932
15) Demolition Works	G15	0,897
16) Workers	G16	0,912

Additionally, Composite reliability is calculated by using the information from LISREL's completely standardized solution and applying the following formula:

$$\rho_c = (\sum\lambda)^2 / [(\sum\lambda)^2 + \sum(\theta)]$$

Where ρ_c = composite reliability, λ = indicator loadings, θ = indicator error variances, and $\sum$ = summation over the indicators of the latent variable (Diamantopoulos and Siguaw 2000).

As could be read also from Table 8.25, composite reliability values for each of the components exceeded Bagozzi and Yi's (1988) 0.60 cut-off, thus, providing additional support for the constructs' acceptable reliability. The proposed second-order construct of "Safety performance of construction sites" should also be considered and its composite reliability was calculated as 0.992, suggesting great reliability.

Table 8.25: Composite reliability of the latent variables

Latent Variables	Abbreviation	Composite Reliability
SAFETY PERFORMANCE	SP	0,995
1) Scaffoldings and Working Platforms	G1	0,898
2) Ladders and Stairs	G2	0,907
3) Working at Height and Protection Against Falling	G3	0,879
4) Lighting and Electricity	G4	0,909
5) Housekeeping, Order and Tidiness	G5	0,932
6) Personal Protective Equipment (PPE)	G6	0,935
7) Fire Prevention/Protection	G7	0,937
8) Hand/Power Tools, Machinery and Devices	G8	0,948
9) Material Handling (Loading, Transport, Unloading, Handling and Storage)	G9	0,948
10)Traffic and Transportation Control	G10	0,923
11) First Aid	G11	0,952
12) Excavation Works	G12	0,939
13) Concrete and Formwork	G13	0,947
14) Welding Works	G14	0,933
15) Demolition Works	G15	0,901
16) Workers	G16	0,917

8.13.2.5 Discriminant Validity Tests for Safety Performance

Discriminant validity refers to the principle that the indicators for different constructs should not be so highly correlated as to conclude that they measure the same thing. Discriminant validity analysis refers to testing statistically whether two measures differ (as opposed to testing convergent validity). The correlations between the measures should be lower than unity in order to achieve discriminant validity.

In this study, results suggested support for discriminant validity. In fact, correlations were found significantly different from unity, suggesting evidence for discriminant validity, according to Steenkamp and van Trijp (1991).

In this study, the correlation matrices calculated for all constructs showed that all intercorrelations were below 0.90, suggesting that there is no multicollinearity (Hair et al. 1998) but indicating that the constructs have discriminant validity. These correlations provide evidence that the measures of first and second-order constructs were different from each other. Intercorrelations for the observable variables of 16 latent dimensions were presented in Tables 8.26, 8.27, ..., 8.41. Intercorrelations for the proposed second-order construct was also presented in Table 8.42.

Table 8.26: Intercorrelations for the observable variables of "G1: Scaffoldings and Working Platforms"

	G1F1	G1F2	G1F3	G1F4	G1F5	G1F6	G1F7	G1F8	G1F9	G1F10	G1F11	G1F12
G1F1	1,000	,547	,473	,408	,450	,421	,502	,459	,525	,445	,497	,370
G1F2	,547	1,000	,614	,332	,526	,377	,280	,413	,372	,465	,478	,358
G1F3	,473	,614	1,000	,380	,549	,400	,380	,461	,328	,459	,481	,393
G1F4	,408	,332	,380	1,000	,480	,491	,428	,298	,417	,345	,353	,329
G1F5	,450	,526	,549	,480	1,000	,539	,392	,442	,461	,321	,452	,360
G1F6	,421	,377	,400	,491	,539	1,000	,555	,417	,455	,216	,408	,365
G1F7	,502	,280	,380	,428	,392	,555	1,000	,503	,521	,314	,354	,425
G1F8	,459	,413	,461	,298	,442	,417	,503	1,000	,461	,357	,382	,436
G1F9	,525	,372	,328	,417	,461	,455	,521	,461	1,000	,286	,340	,399
G1F10	,445	,465	,459	,345	,321	,216	,314	,357	,286	1,000	,547	,298
G1F11	,497	,478	,481	,353	,452	,408	,354	,382	,340	,547	1,000	,467
G1F12	,370	,358	,393	,329	,360	,365	,425	,436	,399	,298	,467	1,000

Table 8.27 Intercorrelations for the observable variables of "G2: Ladders and stairs"

	G2F1	G2F2	G2F3	G2F4	G2F5	G2F6	G2F7	G2F8	G2F9	G2F10
G2F1	1,000	,774	,632	,596	,483	,492	,535	,309	,495	,335
G2F2	,774	1,000	,677	,616	,498	,568	,603	,326	,488	,388
G2F3	,632	,677	1,000	,689	,516	,544	,534	,330	,503	,392
G2F4	,596	,616	,689	1,000	,531	,460	,514	,351	,420	,268
G2F5	,483	,498	,516	,531	1,000	,485	,517	,559	,470	,462
G2F6	,492	,568	,544	,460	,485	1,000	,666	,521	,518	,439
G2F7	,535	,603	,534	,514	,517	,666	1,000	,525	,585	,370
G2F8	,309	,326	,330	,351	,559	,521	,525	1,000	,371	,564
G2F9	,495	,488	,503	,420	,470	,518	,585	,371	1,000	,392
G2F10	,335	,388	,392	,268	,462	,439	,370	,564	,392	1,000

Table 8.28: Intercorrelations for the observable variables of “G3: Working at height and protection against falling”

	G3F1	G3F2	G3F3	G3F4	G3F5	G3F6	G3F7	G3F8	G3F9
G3F1	1,000	,379	,339	,422	,387	,388	,433	,417	,467
G3F2	,379	1,000	,419	,494	,307	,295	,325	,344	,419
G3F3	,339	,419	1,000	,543	,390	,412	,369	,448	,386
G3F4	,422	,494	,543	1,000	,611	,451	,429	,589	,533
G3F5	,387	,307	,390	,611	1,000	,477	,580	,512	,416
G3F6	,388	,295	,412	,451	,477	1,000	,615	,421	,476
G3F7	,433	,325	,369	,429	,580	,615	1,000	,502	,461
G3F8	,417	,344	,448	,589	,512	,421	,502	1,000	,613
G3F9	,467	,419	,386	,533	,416	,476	,461	,613	1,000

Table 8.29: Intercorrelations for the observable variables of “G4: Lighting and electricity”

	G4F1	G4F2	G4F3	G4F4	G4F5	G4F6	G4F7	G4F8	G4F9	G4F10
G4F1	1,000	,604	,419	,353	,421	,319	,417	,411	,466	,395
G4F2	,604	1,000	,445	,362	,545	,419	,445	,438	,549	,434
G4F3	,419	,445	1,000	,615	,495	,416	,439	,597	,458	,508
G4F4	,353	,362	,615	1,000	,579	,474	,476	,566	,445	,478
G4F5	,421	,545	,495	,579	1,000	,692	,621	,535	,581	,549
G4F6	,319	,419	,416	,474	,692	1,000	,675	,560	,559	,536
G4F7	,417	,445	,439	,476	,621	,675	1,000	,614	,557	,409
G4F8	,411	,438	,597	,566	,535	,560	,614	1,000	,532	,560
G4F9	,466	,549	,458	,445	,581	,559	,557	,532	1,000	,588
G4F10	,395	,434	,508	,478	,549	,536	,409	,560	,588	1,000

Table 8.30: Intercorrelations for the observable variables of "G5: Housekeeping, order and tidiness"

	G5F1	G5F2	G5F3	G5F4	G5F5	G5F6	G5F7	G5F8	G5F9	G5F10	G5F11	G5F12
G5F1	1,000	,624	,592	,478	,474	,420	,533	,612	,505	,529	,545	,477
G5F2	,624	1,000	,589	,525	,389	,424	,427	,587	,531	,518	,530	,556
G5F3	,592	,589	1,000	,574	,532	,490	,513	,627	,526	,502	,586	,534
G5F4	,478	,525	,574	1,000	,566	,589	,609	,589	,471	,469	,550	,548
G5F5	,474	,389	,532	,566	1,000	,554	,527	,449	,464	,552	,522	,587
G5F6	,420	,424	,490	,589	,554	1,000	,590	,456	,353	,437	,440	,550
G5F7	,533	,427	,513	,609	,527	,590	1,000	,618	,488	,533	,606	,525
G5F8	,612	,587	,627	,589	,449	,456	,618	1,000	,655	,576	,619	,545
G5F9	,505	,531	,526	,471	,464	,353	,488	,655	1,000	,569	,494	,541
G5F10	,529	,518	,502	,469	,552	,437	,533	,576	,569	1,000	,633	,519
G5F11	,545	,530	,586	,550	,522	,440	,606	,619	,494	,633	1,000	,610
G5F12	,477	,556	,534	,548	,587	,550	,525	,545	,541	,519	,610	1,000

Table 8.31 Intercorrelations for the observable variables of "G6: Personal protective equipment (PPE)"

	G6F1	G6F2	G6F3	G6F4	G6F5	G6F6	G6F7	G6F8	G6F9
G6F1	1,000	,659	,632	,625	,653	,580	,634	,664	,525
G6F2	,659	1,000	,775	,572	,602	,501	,620	,687	,630
G6F3	,632	,775	1,000	,641	,614	,552	,615	,637	,595
G6F4	,625	,572	,641	1,000	,597	,662	,595	,610	,463
G6F5	,653	,602	,614	,597	1,000	,597	,658	,718	,647
G6F6	,580	,501	,552	,662	,597	1,000	,583	,582	,403
G6F7	,634	,620	,615	,595	,658	,583	1,000	,725	,576
G6F8	,664	,687	,637	,610	,718	,582	,725	1,000	,647
G6F9	,525	,630	,595	,463	,647	,403	,576	,647	1,000

Table 8.32: Intercorrelations for the observable variables of "G7: Fire prevention/protection"

	G7F1	G7F2	G7F3	G7F4	G7F5	G7F6	G7F7	G7F8	G7F9	G7F10
G7F1	1,000	,735	,547	,543	,547	,489	,607	,614	,515	,380
G7F2	,735	1,000	,627	,567	,618	,549	,542	,609	,495	,411
G7F3	,547	,627	1,000	,740	,614	,726	,527	,601	,572	,519
G7F4	,543	,567	,740	1,000	,756	,751	,572	,679	,684	,517
G7F5	,547	,618	,614	,756	1,000	,643	,563	,645	,624	,463
G7F6	,489	,549	,726	,751	,643	1,000	,598	,666	,651	,613
G7F7	,607	,542	,527	,572	,563	,598	1,000	,725	,702	,540
G7F8	,614	,609	,601	,679	,645	,666	,725	1,000	,683	,579
G7F9	,515	,495	,572	,684	,624	,651	,702	,683	1,000	,678
G7F10	,380	,411	,519	,517	,463	,613	,540	,579	,678	1,000

Table 8.33: Intercorrelations for the observable variables of "G8: Hand/power tools, machinery and devices"

	G8F1	G8F2	G8F3	G8F4	G8F5	G8F6	G8F7	G8F8	G8F9	G8F10	G8F11	G8F12
G8F1	1,000	,699	,649	,722	,603	,564	,529	,513	,567	,499	,566	,553
G8F2	,699	1,000	,660	,660	,604	,587	,580	,499	,563	,556	,661	,679
G8F3	,649	,660	1,000	,741	,681	,542	,520	,536	,554	,472	,569	,557
G8F4	,722	,660	,741	1,000	,716	,624	,579	,567	,526	,502	,659	,631
G8F5	,603	,604	,681	,716	1,000	,637	,558	,573	,515	,413	,582	,594
G8F6	,564	,587	,542	,624	,637	1,000	,640	,697	,584	,569	,567	,534
G8F7	,529	,580	,520	,579	,558	,640	1,000	,777	,704	,616	,657	,611
G8F8	,513	,499	,536	,567	,573	,697	,777	1,000	,737	,605	,613	,596
G8F9	,567	,563	,554	,526	,515	,584	,704	,737	1,000	,725	,630	,626
G8F10	,499	,556	,472	,502	,413	,569	,616	,605	,725	1,000	,645	,607
G8F11	,566	,661	,569	,659	,582	,567	,657	,613	,630	,645	1,000	,638
G8F12	,553	,679	,557	,631	,594	,534	,611	,596	,626	,607	,638	1,000

Table 8.34: Intercorrelations for the observable variables of “G9: Material handling (loading, transport, unloading, handling and storage)”

	G9F1	G9F2	G9F3	G9F4	G9F5	G9F6	G9F7	G9F8	G9F9	G9F10	G9F11	G9F12
G9F1	1,000	,601	,605	,514	,588	,661	,429	,448	,482	,585	,555	,570
G9F2	,601	1,000	,818	,805	,704	,636	,560	,574	,588	,597	,508	,594
G9F3	,605	,818	1,000	,815	,614	,619	,524	,622	,625	,560	,436	,579
G9F4	,514	,805	,815	1,000	,690	,576	,596	,633	,657	,563	,495	,612
G9F5	,588	,704	,614	,690	1,000	,659	,579	,576	,656	,563	,541	,500
G9F6	,661	,636	,619	,576	,659	1,000	,568	,560	,607	,657	,660	,530
G9F7	,429	,560	,524	,596	,579	,568	1,000	,710	,719	,625	,609	,559
G9F8	,448	,574	,622	,633	,576	,560	,710	1,000	,744	,633	,611	,557
G9F9	,482	,588	,625	,657	,656	,607	,719	,744	1,000	,766	,650	,610
G9F10	,585	,597	,560	,563	,563	,657	,625	,633	,766	1,000	,770	,604
G9F11	,555	,508	,436	,495	,541	,660	,609	,611	,650	,770	1,000	,535
G9F12	,570	,594	,579	,612	,500	,530	,559	,557	,610	,604	,535	1,000

Table 8.35: Intercorrelations for the observable variables of “G10: Traffic and transportation control”

	G10F1	G10F2	G10F3	G10F4	G10F5	G10F6	G10F7	G10F8	G10F9	G10F10	G10F11	G10F12
G10F1	1,000	,482	,571	,590	,449	,427	,589	,552	,578	,449	,560	,567
G10F2	,482	1,000	,465	,411	,550	,359	,384	,350	,412	,215	,415	,411
G10F3	,571	,465	1,000	,734	,370	,342	,523	,480	,498	,410	,440	,408
G10F4	,590	,411	,734	1,000	,419	,346	,501	,467	,458	,424	,516	,491
G10F5	,449	,550	,370	,419	1,000	,525	,529	,489	,493	,233	,424	,436
G10F6	,427	,359	,342	,346	,525	1,000	,693	,655	,629	,272	,505	,523
G10F7	,589	,384	,523	,501	,529	,693	1,000	,788	,718	,447	,553	,592
G10F8	,552	,350	,480	,467	,489	,655	,788	1,000	,737	,538	,524	,599
G10F9	,578	,412	,498	,458	,493	,629	,718	,737	1,000	,487	,631	,579
G10F10	,449	,215	,410	,424	,233	,272	,447	,538	,487	1,000	,481	,425
G10F11	,560	,415	,440	,516	,424	,505	,553	,524	,631	,481	1,000	,606
G10F12	,567	,411	,408	,491	,436	,523	,592	,599	,579	,425	,606	1,000

Table 8.36: Intercorrelations for the observable variables of “G11: First aid”

	G11F1	G11F2	G11F3	G11F4	G11F5	G11F6	G11F7	G11F8
G11F1	1,000	,765	,736	,752	,718	,682	,643	,591
G11F2	,765	1,000	,796	,751	,729	,686	,634	,603
G11F3	,736	,796	1,000	,899	,830	,779	,720	,571
G11F4	,752	,751	,899	1,000	,865	,814	,757	,607
G11F5	,718	,729	,830	,865	1,000	,802	,730	,591
G11F6	,682	,686	,779	,814	,802	1,000	,721	,576
G11F7	,643	,634	,720	,757	,730	,721	1,000	,684
G11F8	,591	,603	,571	,607	,591	,576	,684	1,000

Table 8.37: Intercorrelations for the observable variables of “G12: Excavation works”

	G12F1	G12F2	G12F3	G12F4	G12F5	G12F6	G12F7	G12F8	G12F9	G12F10	G12F11	G12F12
G12F1	1,000	,632	,613	,704	,720	,562	,618	,491	,648	,553	,664	,571
G12F2	,632	1,000	,638	,598	,553	,456	,551	,529	,472	,480	,488	,448
G12F3	,613	,638	1,000	,616	,693	,535	,569	,426	,413	,382	,628	,571
G12F4	,704	,598	,616	1,000	,691	,604	,533	,528	,623	,563	,616	,536
G12F5	,720	,553	,693	,691	1,000	,566	,676	,430	,585	,507	,666	,675
G12F6	,562	,456	,535	,604	,566	1,000	,631	,442	,545	,506	,534	,560
G12F7	,618	,551	,569	,533	,676	,631	1,000	,539	,565	,415	,639	,622
G12F8	,491	,529	,426	,528	,430	,442	,539	1,000	,661	,518	,464	,423
G12F9	,648	,472	,413	,623	,585	,545	,565	,661	1,000	,593	,527	,532
G12F10	,553	,480	,382	,563	,507	,506	,415	,518	,593	1,000	,427	,403
G12F11	,664	,488	,628	,616	,666	,534	,639	,464	,527	,427	1,000	,611
G12F12	,571	,448	,571	,536	,675	,560	,622	,423	,532	,403	,611	1,000

Table 8.38: Intercorrelations for the observable variables of "G13: Concrete and formwork"

	G13F1	G13F2	G13F3	G13F4	G13F5	G13F6	G13F7	G13F8	G13F9	G13F10	G13F11
G13F1	1,000	,713	,685	,629	,513	,586	,661	,601	,601	,653	,606
G13F2	,713	1,000	,794	,617	,414	,510	,649	,637	,696	,632	,548
G13F3	,685	,794	1,000	,698	,462	,599	,636	,674	,687	,677	,602
G13F4	,629	,617	,698	1,000	,623	,575	,625	,631	,585	,652	,636
G13F5	,513	,414	,462	,623	1,000	,589	,553	,574	,438	,588	,564
G13F6	,586	,510	,599	,575	,589	1,000	,759	,697	,570	,641	,604
G13F7	,661	,649	,636	,625	,553	,759	1,000	,747	,698	,670	,599
G13F8	,601	,637	,674	,631	,574	,697	,747	1,000	,680	,658	,576
G13F9	,601	,696	,687	,585	,438	,570	,698	,680	1,000	,644	,458
G13F10	,653	,632	,677	,652	,588	,641	,670	,658	,644	1,000	,654
G13F11	,606	,548	,602	,636	,564	,604	,599	,576	,458	,654	1,000

Table 8.39: Intercorrelations for the observable variables of "G14: Welding works"

	G14F1	G14F2	G14F3	G14F4	G14F5	G14F6	G14F7	G14F8	G14F9	G14F10
G14F1	1,000	,695	,543	,537	,536	,525	,544	,589	,687	,583
G14F2	,695	1,000	,608	,555	,573	,566	,582	,611	,642	,588
G14F3	,543	,608	1,000	,580	,629	,554	,541	,589	,603	,565
G14F4	,537	,555	,580	1,000	,635	,493	,496	,434	,565	,547
G14F5	,536	,573	,629	,635	1,000	,589	,745	,565	,623	,594
G14F6	,525	,566	,554	,493	,589	1,000	,541	,540	,470	,481
G14F7	,544	,582	,541	,496	,745	,541	1,000	,624	,723	,622
G14F8	,589	,611	,589	,434	,565	,540	,624	1,000	,641	,632
G14F9	,687	,642	,603	,565	,623	,470	,723	,641	1,000	,717
G14F10	,583	,588	,565	,547	,594	,481	,622	,632	,717	1,000

Table 8.40: Intercorrelations for the observable variables of “G15: Demolition works”

	G15F1	G15F2	G15F3	G15F4	G15F5	G15F6	G15F7	G15F8	G15F9
G15F1	1,000	,664	,511	,579	,497	,456	,539	,424	,504
G15F2	,664	1,000	,611	,669	,632	,409	,496	,421	,544
G15F3	,511	,611	1,000	,671	,682	,325	,353	,401	,499
G15F4	,579	,669	,671	1,000	,658	,397	,461	,477	,501
G15F5	,497	,632	,682	,658	1,000	,412	,423	,423	,460
G15F6	,456	,409	,325	,397	,412	1,000	,712	,469	,446
G15F7	,539	,496	,353	,461	,423	,712	1,000	,438	,498
G15F8	,424	,421	,401	,477	,423	,469	,438	1,000	,522
G15F9	,504	,544	,499	,501	,460	,446	,498	,522	1,000

Table 8.41: Intercorrelations for the observable variables of “G16: Workers”

	G16F1	G16F2	G16F3	G16F4	G16F5	G16F6	G16F7	G16F8	G16F9	G16F10
G16F1	1,000	,561	,500	,548	,538	,402	,471	,424	,379	,488
G16F2	,561	1,000	,696	,595	,642	,451	,636	,490	,432	,569
G16F3	,500	,696	1,000	,759	,681	,553	,599	,444	,456	,552
G16F4	,548	,595	,759	1,000	,625	,517	,505	,363	,493	,576
G16F5	,538	,642	,681	,625	1,000	,490	,596	,420	,445	,628
G16F6	,402	,451	,553	,517	,490	1,000	,605	,366	,574	,445
G16F7	,471	,636	,599	,505	,596	,605	1,000	,527	,549	,553
G16F8	,424	,490	,444	,363	,420	,366	,527	1,000	,356	,439
G16F9	,379	,432	,456	,493	,445	,574	,549	,356	1,000	,499
G16F10	,488	,569	,552	,576	,628	,445	,553	,439	,499	1,000

Table 8.42: Intercorrelations for the second-order latent variables of "SP: Safety Performance"

	G1	G2	G3	G4	G5	G6
G1	1.00					
G2	0.63	1.00				
G3	0.69	0.70	1.00			
G4	0.72	0.73	0.80	1.00		
G5	0.67	0.68	0.75	0.77	1.00	
G6	0.67	0.68	0.75	0.77	0.72	1.00
G7	0.65	0.66	0.73	0.75	0.70	0.70
G8	0.71	0.72	0.80	0.82	0.77	0.77
G9	0.74	0.75	0.82	0.85	0.79	0.79
G10	0.73	0.74	0.82	0.84	0.79	0.79
G11	0.52	0.52	0.57	0.59	0.55	0.55
G12	0.74	0.75	0.82	0.85	0.79	0.79
G13	0.69	0.70	0.76	0.79	0.74	0.74
G14	0.74	0.75	0.82	0.85	0.79	0.79
G15	0.73	0.74	0.81	0.84	0.79	0.79
G16	0.68	0.69	0.75	0.78	0.73	0.73

Table 8.42: Intercorrelations for the second-order latent variables of "SP: Safety Performance" (Cont.'d)

	G7	G8	G9	G10	G11	G12
G7	1.00					
G8	0.75	1.00				
G9	0.77	0.84	1.00			
G10	0.77	0.84	0.87	1.00		
G11	0.54	0.59	0.61	0.61	1.00	
G12	0.77	0.84	0.87	0.87	0.61	1.00
G13	0.72	0.79	0.81	0.81	0.57	0.81
G14	0.77	0.85	0.87	0.87	0.61	0.87
G15	0.77	0.84	0.86	0.86	0.61	0.86
G16	0.71	0.78	0.80	0.80	0.56	0.80

Table 8.42: Intercorrelations for the second-order latent variables of "SP: Safety Performance" (Cont.'d)

	G13	G14	G15	G16
G13	1.00			
G14	0.81	1.00		
G15	0.81	0.87	1.00	
G16	0.75	0.80	0.79	1.00

8.13.3 Summary of the assessment of the measurement model

The assessment of the measurement model by SEM was presented inclusive of content validity, unidimensionality, convergent validity, goodness of fit, reliability (internal consistency and composite reliability), and discriminant validity testings. Analysis of the measurement model was carried out using factor analysis by first-order and second-order confirmatory factor analysis (CFA) for the assessment of unidimensionality, convergent validity, reliability, and discriminant validity. Results of the measurement model by SEM showed that, content validity was achieved, unidimensionality of both first-order and second-order factor structure was evidenced and held, convergent validity of both first-order factor structure was supported by high factor loadings and acceptable goodness of fitness indices, reliability was sustained by greater Cronbach's alpha and composite reliability values, discriminant validity was evidenced with all correlations significantly differed from unity and suggesting no multicollinearity.

After the assessment of the measurement model, the following part will present the assessment of the structural model.

8.14 Assessment of structural model

8.14.1 Introduction

In the previous chapters, a total of 168 observable variables in 16 latent dimensions affecting "safety performance of construction sites" were achieved through literature review and face-to-face interviews with 15 construction safety professionals. After determining the observable variables and latent dimensions affecting safety performance of construction sites, a final safety performance model was formed and the research hypotheses were determined accordingly. In this part, the hypothesized second-order construct model will be tested statistically and the path coefficients indicating the strength of the assumed relations will be analyzed. The structural component of the SEM model which represents the second-order construct "safety performance of construction sites" and its first order constructs (dimensions) will be explained. The extent to which the second-order factorial model described the actual data, both hypothesized measurement and structural model will be tested and proposed measurement and structural model equations proposed by LISREL will be presented.

8.14.2 Research hypotheses

According to the final research model, 17 different research hypotheses (H1-H17) were determined previously.

8.14.3 Hypothesized second-order factor structural model

A second-order factor structural model was constructed in order to assess the effects (weights) of the latent dimensions to the "Safety Performance of Construction Sites". The hypothesized model was depicted in Figure 8.2. 168 observable variables shown in regular boxes, whereas the latent factors (first and second-order factors) were shown in ellipses.

The model hypothesized that the second-order latent factor “Safety Performance of Construction Sites” accounts for the relationship of the 16 first-order latent factors: (G1): “Scaffoldings and working platforms”, (G2): “Ladders and stairs”, (G3): “Working at height and protection against falling”, (G4): “Lighting and electricity”, (G5): “Housekeeping, order and tidiness”, (G6): “Personal protective equipment (PPE)”, (G7): “Fire prevention/protection”, (G8): “Hand/power tools, machinery and devices”, (G9): “Material handling (loading, transport, unloading, handling and storage)”, (G10): “Traffic and transportation control”, (G11): “First aid”, (G12): “Excavation works”, (G13): “Concrete and formwork”, (G14): “Welding works”, (G15): “Demolition works”, and (G16): “Workers”.

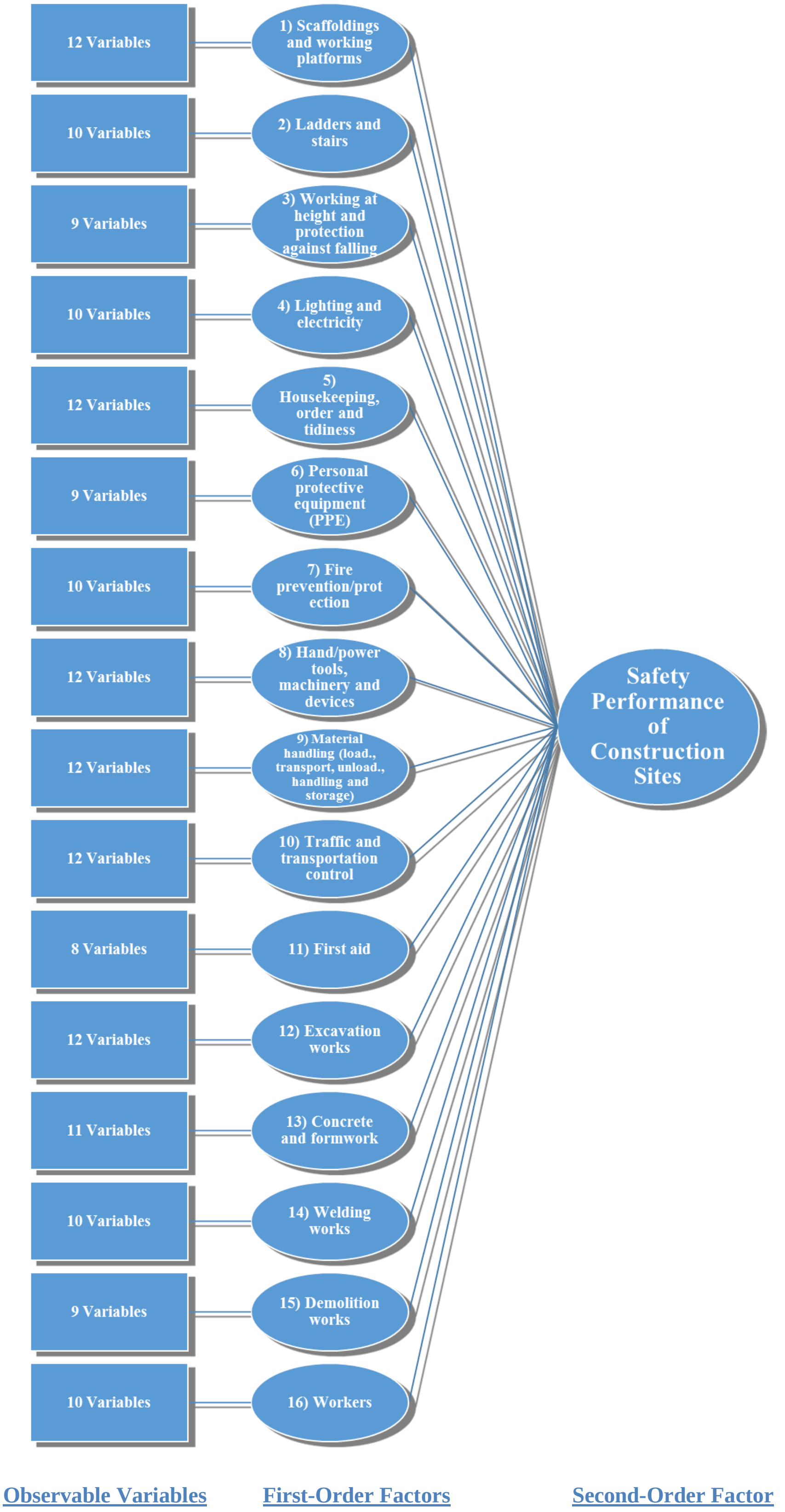


Figure 8.2: Hypothesized second-order factor structural model for "Safety Performance of Construction Sites"

8.14.4 The measurement model

The measurement model consisted of the hypothesized relationships among 168 observable variables and the 16 first-order factors (G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11, G12, G13, G14, G15, G16). The equations calculated by LISREL corresponding to the measurement model (associations between the latent variables and respective observable variables) were presented in Appendix E.

Close to each equation there was also information on the variance of the measurement error (error variance in measurement equations). For example, in the measurement equation output linking observable variable G6F5 and first-order factor G6 was demonstrated in Table 8.43:

Table 8.43: The measurement equation output linking observable variable G6F5 and first-order factor G1 (as example)

G6F5 = 0.94*G6, Errorvar.= 0.022 , R^2 = 0.68		
(0.073)	(0.0026)	
12.84	8.23	

Where:

- the standard error that corresponded to the regression coefficient (0.94) was (0.073) and the t-value was 12.84,
- in relation to the error variance (0.022), the standard error was 0.0026 and the t-value 8.23.

This output section also included the squared multiple correlations (R^2) for each equation, that is, the amount of variance in the dependent variables explained by independent variables.

8.14.5 The structural model

The structural model focused on the relationship between the 16 first-order factors and the second-order factor “Safety Performance of Construction Sites”. The equations calculated by LISREL representing the structural model (associations between first-order and second-order factors) were presented in Appendix F.

Close to each equation there was also information on the variance of the residual term (error variance in structural equations). For example, in the structural equation output linking first-order factor G4 and the second-order factor SP was demonstrated in Table 8.44:

Table 8.44: The structural equation output linking first-order factor G4 and the second-order factor SP (as example)

G4 = 0.13*SP,	Errorvar.= 0.0032	, R^2 = 0.83
(0.016)	(0.00091)	
7.76	3.49	

Where:

- the standard error that corresponded to the regression coefficient (0,13) was (0.016) and the t-value was 7.76,
- in relation to the error variance (0.0032), the standard error was 0.00091 and the t-value 3.49.

This output section also included the squared multiple correlations (R^2) for each equation, that is, the amount of variance in the dependent variables (factors) explained by independent variables (factors).

The results of second-order factor structural model for “Safety Performance of Construction Sites” was shown in Table 8.45 below.

Table 8.45: Results of second-order factor structural model for "Safety Performance of Construction Sites"

Second order Factor	**First order Factors**	**Standardized Factor Loadings**	**Standard Error**	**T- value**	**R^2 value**
Safety Performance of Construction Sites (SP)	G1	0,79	0,014	8,70	0,62
	G2	0,83	0,015	8,69	0,69
	G3	0,88	0,014	7,96	0,77
	G4	0,91	0,016	7,76	0,83
	G5	0,85	0,016	9,63	0,72
	G6	0,85	0,018	11,02	0,73
	G7	0,83	0,014	8,91	0,69
	G8	0,90	0,016	10,67	0,81
	G9	0,94	0,018	10,56	0,89
	G10	0,94	0,015	11,12	0,88
	G11	0,65	0,015	8,41	0,43
	G12	0,93	0,014	12,50	0,87
	G13	0,88	0,015	11,15	0,77
	G14	0,94	0,016	11,78	0,89
	G15	0,93	0,013	10,47	0,87
	G16	0,86	0,013	9,36	0,74

Hair et al. (2010) recommended that standardized factor loading should be greater than 0.5. All the paths from second order factor to the first order factors were significant. The minimum value of standardized factor loading belonged to G11 with the value 0.65. All standardized factor loadings were greater than 0.5, satisfying the recommended values as shown in Table 8.45.

The empirically tested second-order factor structural model for "Safety Performance of Construction Sites" with the unstandardized parameter estimates was shown in Figure 8.3.

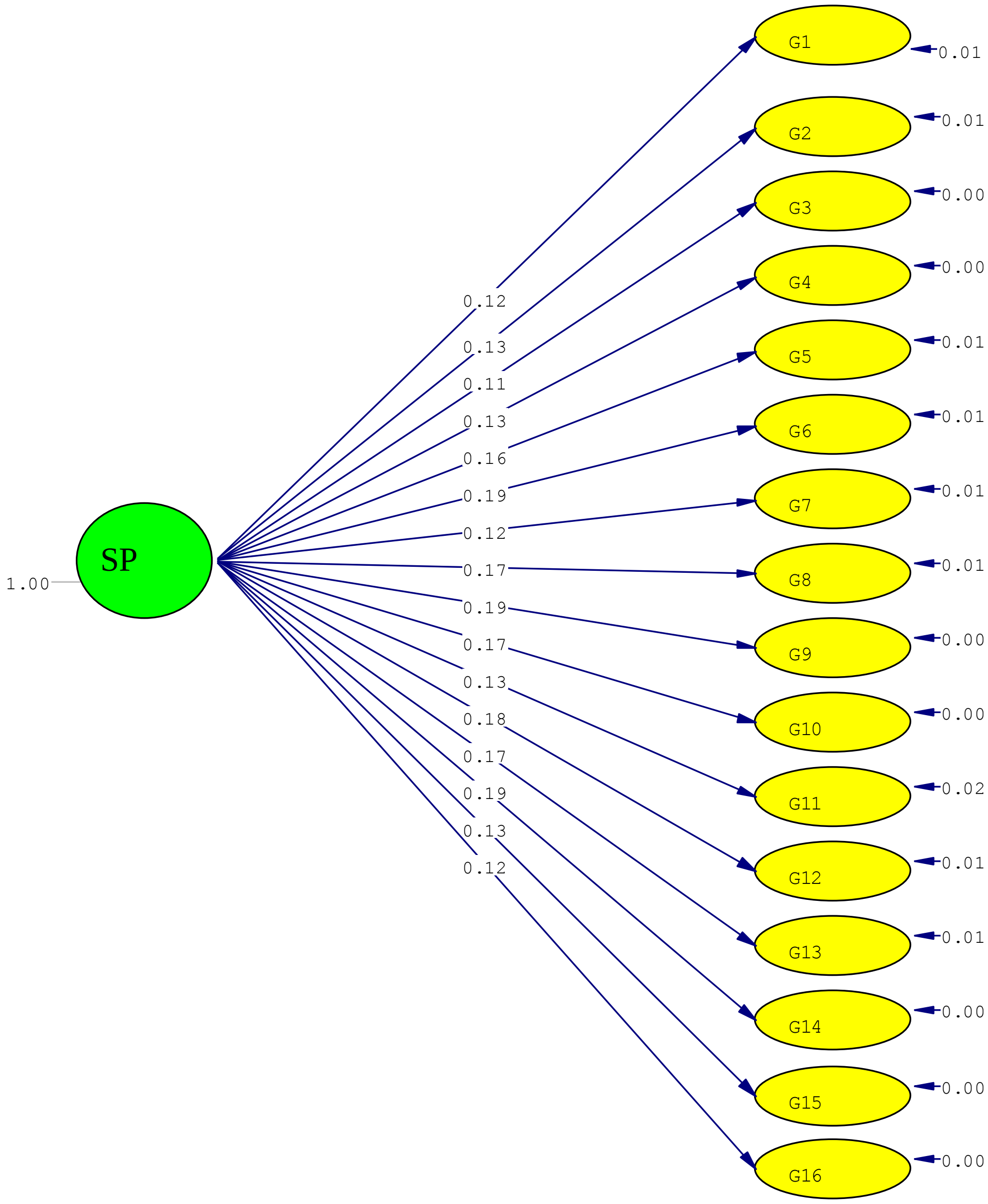


Figure 8.3: Second-order factor structural model for "Safety Performance of Construction Sites" (Unstandardized Estimates)

The empirically tested second-order factor structural model for "Safety Performance of Construction Sites" with the standardized parameter estimates was shown in Figure 8.4.

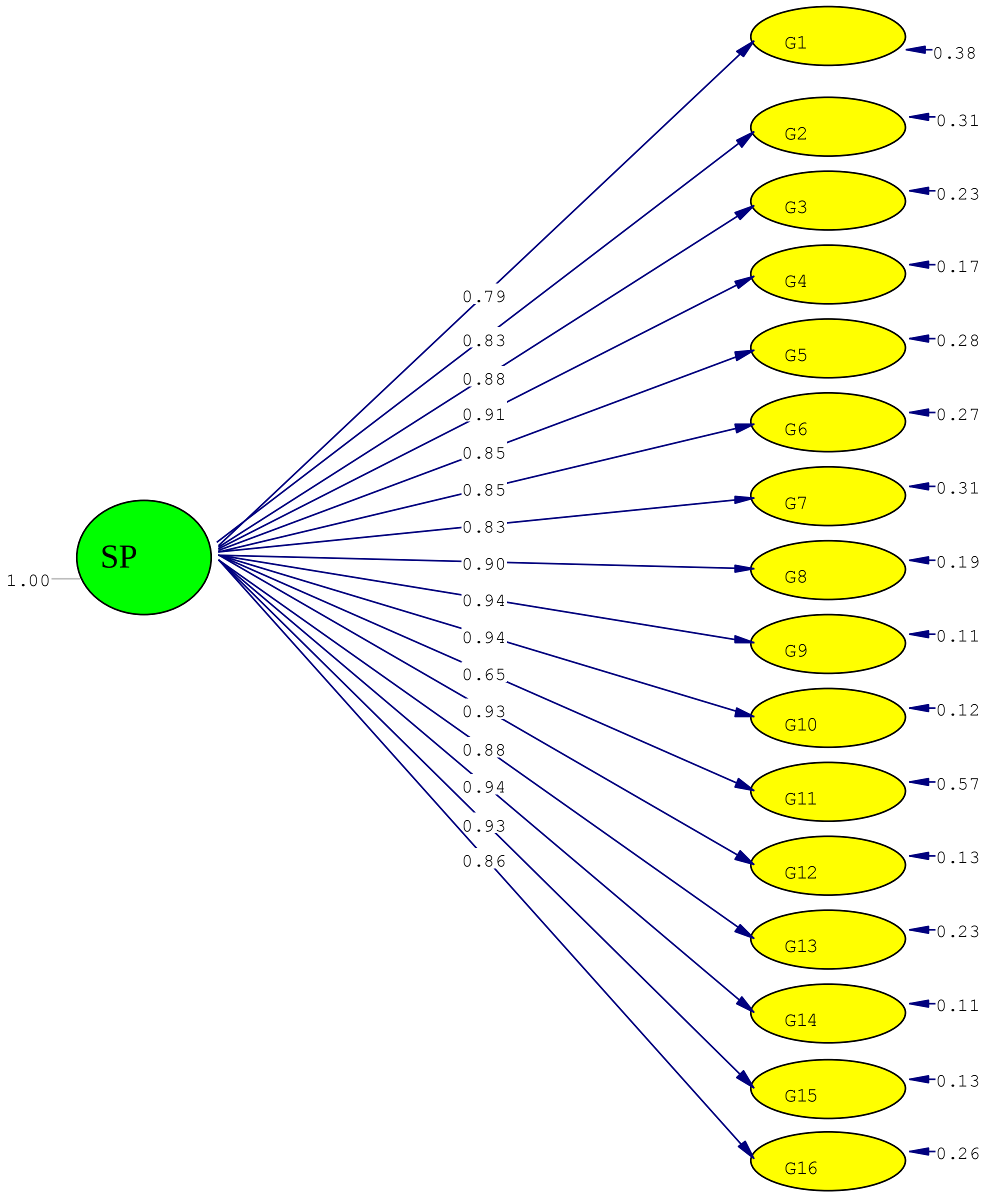


Figure 8.4: Second-order factor structural model for “Safety Performance of Construction Sites” (Standardized)

8.14.6 Assessment of overall goodness of fit (second-order factor SP)

The calculated overall second-order model fit statistics in LISREL, were within the generally accepted thresholds, and satisfied the recommendations. In fact, although the Chi-square test was significant (χ^2 = 25060.26, p = 0.0), the ratio chi-square/degrees of freedom was below 2 (dof = 13798, χ^2 /dof = 1.82)—normally a ratio in the range of 2–1 (Hair et al. 1998) or 3–1 (Kline 1998; Jashapara 2003; Cote et al. 2001), was indicative of a good and acceptable fit.

The non-normed fit index (NNFI = 0.95), and the comparative fit index (CFI = 0.95), as well as the root mean square error of approximation (RMSEA = 0.068) were indicating good fit (Diamantopoulos and Siguaw 2000; MacCallum et al. 1996; Bentler 1989). As presented in Table 8.46, all of the χ^2 /dof, NNFI, CFI and RMSEA revealed good fit and complied with the recommendations.

Table 8.46: Fit indices for the proposed second-order factor structural model

Fit indices for the proposed safety performance model	Recommended value	Proposed Second-order Factor Structural Model
Non-normed fit index (NNFI)	0 (no fit) to 1 (perfect fit)	0,95
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0,95
Root mean square error of approximation (RMSEA)	< 0.10 indicates good fit	0,068
$\chi2$/dof	< 3	1,82

8.14.7 Testing results of the research hypotheses

According to the final research model, testing results of 17 different research hypotheses (H1-H17) were as follows:

H1: A model consisting of 16 latent variables were designed in order to measure their effects (weights) on safety performance of construction sites. 16 latent variables (“Scaffoldings and working platforms”, “Ladders and stairs”, “Working at height and protection against falling”, “Lighting and electricity”, “Housekeeping, order and tidiness”, “Personal protective equipment (PPE)”, “Fire prevention/protection”, “Hand/power tools, machinery and devices”, “Material handling (loading, transport, unloading, handling and storage)”, “Traffic and transportation control”, “First aid”, “Excavation works”, “Concrete and formwork”, “Welding works”, “Demolition works”, and “Workers”) predict “Safety performance of construction sites”.

Hypothesis (H1) was supported. The relationships of the propriety of all first-order factors and the second-order factor SP: “Safety performance of construction sites” were direct and significantly positive as shown in Table 8.45. The unidimensionality, content validity, convergent validity, goodness of fit, reliability (internal consistency and composite reliability), and discriminant validity tests were implemented for each construct and for the whole second-order factor structural model, and all of the results were quite satisfactory.

H2: The conformity of “Scaffoldings and working platforms” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H2) was supported. The relationship between the conformity of G1: “Scaffoldings and working platforms” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G1 was 0.79 (Figure 8.4). In other words, 1 unit of increase in the conformity of “Scaffoldings and working platforms” led to an approximately 0.79 unit of increase in “Safety performance of construction sites” with R^2=0.62.

H3: The conformity of “Ladders and stairs” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H3) was supported. The relationship between the conformity of G2: “Ladders and stairs” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G2 was 0.83 (Figure 8.4). In other words, 1 unit of increase in the conformity of “Ladders and stairs” led to an approximately 0.83 unit of increase in “Safety performance of construction sites” with R^2=0.69.

H4: The appropriateness of “Working at height and protection against falling” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H4) was supported. The relationship between the conformity of G3: “Working at height and protection against falling” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G3 was 0.88 (Figure 8.4). In other words, 1 unit of increase in the appropriateness of “Working at height and protection against falling” led to an approximately 0.88 unit of increase in “Safety performance of construction sites” with R^2=0.77.

H5: The propriety of “Lighting and electricity” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H5) was supported. The relationship between the propriety of G4: “Lighting and electricity” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G4 was 0.91 (Figure 8.4). In other words, 1 unit of increase in the propriety of “Lighting and electricity” led to an approximately 0.91 unit of increase in “Safety performance of construction sites” with R^2=0.83.

H6: The conformity of "Housekeeping, order and tidiness" has a positive direct effect on "Safety performance of construction sites".

Hypothesis (H6) was supported. The relationship between the conformity of G5: "Housekeeping, order and tidiness" and SP: "Safety performance of construction sites" was direct and significantly positive. The standardized path coefficient from SP to G5 was 0.85 (Figure 8.4). In other words, 1 unit of increase in the conformity of "Housekeeping, order and tidiness" led to an approximately 0.85 unit of increase in "Safety performance of construction sites" with R^2=0.72.

H7: The propriety of "Personal protective equipment (PPE)" has a positive direct effect on "Safety performance of construction sites".

Hypothesis (H7) was supported. The relationship between the propriety of G6: "Personal protective equipment (PPE)" and SP: "Safety performance of construction sites" was direct and significantly positive. The standardized path coefficient from SP to G6 was 0.85 (Figure 8.4). In other words, 1 unit of increase in the propriety of "Personal protective equipment (PPE)" led to an approximately 0.85 unit of increase in "Safety performance of construction sites" with R^2=0.73.

H8: The conformity of "Fire prevention/protection" has a positive direct effect on "Safety performance of construction sites".

Hypothesis (H8) was supported. The relationship between the conformity of G7: "Fire prevention/protection" and SP: "Safety performance of construction sites" was direct and significantly positive. The standardized path coefficient from SP to G7 was 0.83 (Figure 8.4). In other words, 1 unit of increase in the conformity of "Fire prevention/protection" led to an approximately 0.83 unit of increase in "Safety performance of construction sites" with R^2=0.69.

H9: The propriety of “Hand/power tools, machinery and devices” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H9) was supported. The relationship between the propriety of G8: “Hand/power tools, machinery and devices” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G8 was 0.90 (Figure 8.4). In other words, 1 unit of increase in the propriety of “Hand/power tools, machinery and devices” led to an approximately 0.90 unit of increase in “Safety performance of construction sites” with R^2=0.81.

H10: The propriety of “Material handling (loading, transport, unloading, handling and storage)” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H10) was supported. The relationship between the propriety of G9: “Material handling (loading, transport, unloading, handling and storage)” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G9 was 0.94 (Figure 8.4). In other words, 1 unit of increase in the propriety of “Material handling (loading, transport, unloading, handling and storage)” led to an approximately 0.94 unit of increase in “Safety performance of construction sites” with R^2=0.89.

H11: The conformity of “Traffic and transportation control” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H11) was supported. The relationship between the conformity of G10: “Traffic and transportation control” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G10 was 0.94 (Figure 8.4). In other words, 1 unit of increase in the conformity of “Traffic and transportation control” led to an approximately 0.94 unit of increase in “Safety performance of construction sites” with R^2=0.88.

H12: The propriety of “First aid” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H12) was supported. The relationship between the propriety of G11: “First aid” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G11 was 0.65 (Figure 8.4). In other words, 1 unit of increase in the propriety of “First aid” led to an approximately 0.65 unit of increase in “Safety performance of construction sites” with R^2=0.43.

H13: The appropriateness of “Excavation works” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H13) was supported. The relationship between the conformity of G12: “Excavation works” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G12 was 0.93 (Figure 8.4). In other words, 1 unit of increase in the appropriateness of “Excavation works” led to an approximately 0.93 unit of increase in “Safety performance of construction sites” with R^2=0.87.

H14: The conformity of “Concrete and formwork” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H14) was supported. The relationship between the conformity of G13: “Concrete and formwork” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G13 was 0.88 (Figure 8.4). In other words, 1 unit of increase in the conformity of “Concrete and formwork” led to an approximately 0.88 unit of increase in “Safety performance of construction sites” with R^2=0.77.

H15: The propriety of “Welding works” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H15) was supported. The relationship between the propriety of G14: “Welding works” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G14 was 0.94 (Figure 8.4). In other words, 1 unit of increase in the propriety of “Welding works” led to an approximately 0.94 unit of increase in “Safety performance of construction sites” with R^2=0.89.

H16: The propriety of “Demolition works” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H16) was supported. The relationship between the propriety of G15: “Demolition works” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G15 was 0.93 (Figure 8.4). In other words, 1 unit of increase in the propriety of “Demolition works” led to an approximately 0.93 unit of increase in “Safety performance of construction sites” with R^2=0.87.

H17: The conformity of “Workers” has a positive direct effect on “Safety performance of construction sites”.

Hypothesis (H17) was supported. The relationship between the conformity of G16: “Workers” and SP: “Safety performance of construction sites” was direct and significantly positive. The standardized path coefficient from SP to G16 was 0.86 (Figure 8.4). In other words, 1 unit of increase in the propriety of “Workers” led to an approximately 0.86 unit of increase in “Safety performance of construction sites” with R^2=0.74.

8.14.8 Summary of the assessment of the structural model

After achieving the validity of the measurement model, the equations calculated by LISREL corresponding to the measurement model (associations between the latent variables and respective observable variables) and the structural model (associations between first-order and second-order factors) were presented (See Appendix E and Appendix F). The assessment of the structural model including the testing of hypothesized second-order factor structural model by structural equation modeling (SEM) as a confirmatory assessment of structural validity, and the testing of the research hypotheses were explained comprehensively. Hypothesis testing results showed that, all of the research hypotheses were supported.

8.15 Chapter summary

This chapter presented the basics of structural equation modeling. Although the presented material only covered a part of the body of structural equation modeling in general, it was designed for a reader to understand the conceptual framework of the SEM methodologies and processes implemented in this study.

Structural equation modeling was utilized to achieve objectives of the current thesis proposal to study the relationships between determinants of safety performance, and to develop and validate a multidimensional safety performance model.

SEM was selected as an analysis and testing tool for the current study because of its unique features over other multivariate techniques (Biddle and Marlin 1987; Myers 1990; Greene 1990; Crowley and Fan 1997; Jackson et al. 2005; Ullman 2006; Bentler 2006; Byrne 2006; Schreiber et al. 2006; Garson 2008; Byrne 2009) such as:

- SEM provided the researchers with the possibility of studying problems which were neither observable nor quantifiable through the concept of latent variables.
- SEM allowed testing of hypothesis at the construct level with adequate accuracy.
- While other methods dealed only with measured observed variables, SEM enabled creation and estimation of latent variables underlying the observed variables, and also examination of their interrelationships.
- SEM could examine a series of separate, but interdependent, multiple regression equations simultaneously by specifying the structural model.
- SEM enabled the analysis of highly complex models containing diverse types of relations and high number of variables.
- Direct and indirect causal effects and covariances among variables could be investigated by SEM, instead of studying all variables under the same unique level.
- Other comparable statistic methods allowed for limited number of hypothesis to be evaluated.
- In contrast to ordinary regression methods, SEM took into consideration of the possible errors in measurement of observed variables. The assumption of perfect measurement of variables was not a realistic approach, it might affect the reliability of analysis and lead to serious inaccuracies, especially when errors were fairly large. Measurement errors could increase model error variance, and lead to biased estimates. This shortcoming of alternative methods was eliminated in SEM to take the effects of poorly measured data into account.
- SEM took a confirmatory rather than an exploratory approach to data analysis. This enabled the evaluation of hypotheses. Various fit indices and validity/reliability tests were available for

> examining the compatibility of the developed models and assumed relationships with the sample data. An a priori theoretical model could be tested with empirical data by SEM. In contrast, most other multivariate techniques were descriptive and exploratory in nature, making them less appropriate for model testing.

In this chapter, firstly, a brief information about structural equation modeling and its assumptions, advantages, terms, components, processes, applications in the construction industry, application to the current study and selected software packages of SEM, and brief information of LISREL were mentioned.

Then, for the analysis of the proposed model by structural equation modeling, the choice of the type of the input matrix, estimation techniques, analysis approach, selection of goodness of fit indices, data screening (missing values), examination of univariate and multivariate normality, and sample size requirements were explained in a detailed manner.

After having described the analysis of the proposed model by structural equation modeling, the assessment of the measurement model by SEM was presented inclusive of content validity, unidimensionality, convergent validity, goodness of fit, reliability (internal consistency and composite reliability), discriminant validity testings. Analysis of the measurement model was carried out using factor analysis by first-order and second-order confirmatory factor analysis (CFA) for the assessment of unidimensionality, convergent validity, reliability, and discriminant validity.

After achieving the validity of the measurement model, the equations calculated by LISREL corresponding to the measurement model (associations between the latent variables and respective observable variables) and the structural model (associations between first-order and second-order latent variables) were presented (See Appendix E and Appendix F).

Finally, the assessment of the structural model including the testing of hypothesized second-order factor structural model by structural equation modeling (SEM) as a confirmatory assessment of structural validity, and the testing of the research hypotheses were explained comprehensively. Hypothesis testing results showed that, all of the research hypotheses were supported.

CHAPTER 9

THE DEVELOPMENT OF THE FORMULATION OF THE SAFETY PERFORMANCE INDEX OF CONSTRUCTION SITES AND IMPLEMENTATION OF THE FORMULA IN CASE STUDIES

9.1 Introduction

In this chapter, for the development of the Safety Performance Index assessment tool, the adopted methodology from Yoo and Donthu (2001) and Avcılar (2010) will be presented. Accordingly, calculations will be performed based on the findings of the previous chapters, and formulation of the Safety Performance Index of Construction Sites will be explained in detail. Case studies will be conducted at 11 international construction sites to assess their safety performance indices. Brief information will be given about the safety performance evaluation forms and how to fill at the sites by the safety engineers of the companies. Detailed information regarding the calculation of the Site Safety Performance Index of Case studies will be given and the items utilized in the formula will be explained. Possible scenarios and their reflection to the developed formula will be explained. Then, levels of latent dimensions affecting safety performance and the Site Safety Performance Indices of 11 Case studies will be benchmarked and results will be demonstrated. Finally a proposal of a short (simple) model (48 observed variables in 16 latent dimensions) as an alternative to the full model (168 observed variables in 16 latent dimensions) will be explained and its advantages will be mentioned.

9.2 Calculations of the relative weights of the 16 different latent dimensions of "Safety Performance of construction sites"

In this study, a 168 observable variables in 16 latent dimensions measure was suggested as a scale of "Safety performance of construction sites". Adding up the respondents' scores of the 168 observable variables of the "Safety performance of construction sites" might not be an appropriate way to develop a Safety Performance Index, because they were not evenly distributed among the 16 latent dimensions. More important, it was found in the previous chapters that the 16 latent dimensions were contributing differently to "Safety performance of construction sites".

To develop the formula for a single Safety Performance Index, the relationships between the 16 latent dimensions and "Safety performance of construction sites" should be considered. Therefore, a similar methodology that Yoo and Donthu (2001) and Avcılar (2010) used in their studies was adopted in this study in the development of the formulation for "Safety Performance Index". Yoo and Donthu (2001) and Avcılar (2010) both performed second-order factorial confirmatory factor analyses to evaluate the effects of each different latent dimensions in the formulation of for a single "Multidimensional Brand Equity Index". According to the methodology that Yoo and Donthu (2001) and Avcılar (2010) used in their studies, it was suggested that the relative weight of a dimension was the portion of the path coefficient of that dimension to the sum of the all latent dimensions' path coefficients.

In this study, all causal paths of the second-order factor SP: "Safety performance of construction sites" to the first-order factors (16 latent dimensions) were explained in previous parts. The standardized path coefficients from "Safety performance of construction sites" to all first-order factors (16 latent dimensions) were found to be direct and significant. The standardized path coefficients of 16 latent dimensions affecting SP: "Safety performance of construction sites" were as follows:

- G1: the propriety of "Scaffoldings and working platforms" was 0.79,
- G2: the conformity of "Ladders and stairs" was 0.83,
- G3: the conformity of "Working at height and protection against falling" was 0.88,
- G4: the propriety of "Lighting and electricity" was 0.91,
- G5: the conformity of "Housekeeping, order and tidiness" was 0.85,
- G6: the propriety of "Personal protective equipment (PPE)" was 0.85,
- G7: the conformity of "Fire prevention/protection" was 0.83,
- G8: the propriety of "Hand/power tools, machinery and devices" was 0.90,
- G9: the propriety of "Material handling (loading, transport, unloading, handling and storage)" was 0.94,
- G10: the conformity of "Traffic and transportation control" was 0.94,
- G11: the propriety of "First aid" was 0.65,
- G12: the conformity of "Excavation works" was 0.93,
- G13: the conformity of "Concrete and formwork" was 0.88,
- G14: the propriety of "Welding works" was 0.94,
- G15: the propriety of "Demolition works" was 0.93, and
- G16: the conformity of "Workers" was 0.86.

These path coefficients were utilized in the calculation of relative weights of the 16 different latent dimensions when computing the Safety Performance Index. An example, demonstrating the calculation of relative weight of the latent dimension G1 were explained as follows: For example, the relative weight of G1: the propriety of "Scaffoldings and working platforms" was 0.0568, resulting from 0.79 / (0.79 + 0.83 + 0.88 + 0.91 + 0.85 + 0.85 + 0.83 + 0.90 + 0.94 + 0.94 + 0.65 + 0.93 + 0.88 + 0.94 + 0.93 + 0.86) = 0.0568. The calculated relative weights for all of the latent dimensions of "Safety performance of construction sites" were shown in Table 9.1.

Table 9.1: The calculated relative weights for all of the latent dimensions of "Safety performance of construction sites"

Abbreviation	Latent dimensions of "Safety performance of construction sites"	Standardized path coefficients	Relative weights of First-order factors
G1	"Scaffoldings and working platforms"	0,79	0,0568
G2	"Ladders and stairs"	0,83	0,0597
G3	"Working at height and protection against falling"	0,88	0,0633
G4	"Lighting and electricity"	0,91	0,0654
G5	"Housekeeping, order and tidiness"	0,85	0,0611
G6	"Personal protective equipment (PPE)"	0,85	0,0611
G7	"Fire prevention/protection"	0,83	0,0597
G8	"Hand/power tools, machinery and devices"	0,90	0,0647
G9	"Material handling (loading, transport, unloading, handling and storage)"	0,94	0,0676
G10	"Traffic and transportation control"	0,94	0,0676
G11	"First aid"	0,65	0,0467
G12	"Excavation works"	0,93	0,0669
G13	"Concrete and formwork"	0,88	0,0633
G14	"Welding works"	0,94	0,0676
G15	"Demolition works"	0,93	0,0669
G16	"Workers"	0,86	0,0618
TOTAL		**13,91**	**1,0000**

9.3 The development of the formulation of the “safety performance index of construction sites”

The equations used in the development of the formulation of “Multidimensional Brand Equity Index” by Yoo and Donthu (2001) and Avcılar (2010) was shown in Table 9.2 below.

Table 9.2: The equations used in the formulation of the “Multidimensional Brand Equity Index” by Yoo and Donthu (2001) and Avcılar (2010)

Brand Equity Index = $\Sigma(WD_i * MD_i)$
WD_i= The weight of each dimension,
MD_i= The mean of dimension.
WD= The weight of the dimension= (SFLD/ SSFLD),
SFLD=Standardized factor loading of the dimension,
SSFLD= Summation of the standardized factor loadings of all latent dimensions.

In this study, a similar methodology that Yoo and Donthu (2001) and Avcılar (2010) used was adopted in the development of the formulation of “Safety performance Index”. The developed formulation of the Safety Performance Index of Construction Sites was presented in Table 9.3. Explanations of terms included in the formula were presented below.

Table 9.3: The developed formulation of the Safety Performance Index of Construction Sites

Safety Performance Index *of Construction Sites* **= $\Sigma(WMD_i * UWD_i)$**
Safety Performance Index *of Construction Sites* **= $\Sigma(UWOj * SEj * UWD_i)$**

Where:

WMD_i= The weighted mean of the site observations of each latent dimension of "Safety performance of construction sites" = [Σ (UWOj * SEj)] / [Σ UWOj],

where Σ UWOj = 1

i= 1, 2, …,16

j= 1, 2, …., total number of observed variables in the corresponding latent dimension

UWOj = Updated relative weight of the observed variable $_j$ (refer to factor analysis results) = [1 / Σ (WOj)] * WOj

SEj = Site evaluation of the observed variable $_j$ (scale: 0-100 where 0: Conformity is minimum, 100: Conformity is maximum)

WOj = Relative weight of the observed variable $_j$ (refer to factor analysis results) = FLj / Σ (FLj)

FLj = Factor loading of the observed variable $_j$

UWDi = The updated relative weight of latent dimension i of "Safety performance of construction sites" = [1 / Σ (WDi)] * WDi]

n= 16 (total number of latent dimensions (first-order factors) affecting safety performance of construction sites)

WDi= Relative weight of latent dimension i of "Safety performance of construction sites" = (SPCDi) / Σ (SPCDi)

SPCDi= Standardized path coefficient of the latent dimension i of "Safety performance of construction sites"

Σ SPCDi= Summation of the standardized path coefficients of all latent dimensions of "Safety performance of construction sites"

Safety Performance Index ***of Construction Sites*** = Σ([1 / Σ ((SPCDi) / Σ (SPCDi))] * (SPCDi) / Σ (SPCDi)]* [1 / Σ (FLj / Σ (FLj))] * (FLj / Σ (FLj)) * SEj)

9.4 Implementation of the safety performance index formula in case studies

To assess the safety performance of 11 different international construction sites, investigations were made by safety professionals of construction companies. The evaluation forms (including the full list of 168 observed variables in 16 latent dimensions of safety performance) which were filled taking into account of a scale between 0 to 100, where 0: Conformity is minimum, 100: Conformity is maximum, NA: If not applicable at the construction sites by safety engineers of the companies working for the Case study projects was shown in Appendix G.

9.4.1 Case study #1

The Site Safety Performance Index of Case study #1 was calculated as 82,1587%. Detailed information regarding the calculation of the Site Safety Performance Index was given in Appendix H:

Explanations of the formulas in the Appendix H were listed as follows:

- **Column FLj:** In this table, observed variables were listed in the descending order with respect to their factor loadings (FL_j).

- **Column WOj:** Relative weight of the observed variable j was calculated by the formula below:

  WOj = FLj / Σ (FLj); where FLj = Factor loading of the observed variable $_j$.

  As an example: Relative weight of the observed variable G1F5 was calculated as:
  (WO_{G1F5}) = (FL_{G1F5}) / Σ (FLj;

  Where j= total number of observed variables in the corresponding latent dimension.

  0,0911 = 0,71 / 7,79

- **Column UWOj:** Updated relative weight of the observed variable j was calculated by the formula below:

  UWOj = [1 / Σ (WOj)] * WOj.

As an example: Updated relative weight of the observed variable G1F5 was calculated as:

$(UWO_{G1F5}) = [1 / \Sigma (WOj)] * WO_{G1F5}$;

Where j= total number of observed variables in the corresponding latent dimension.

0,0911 = 1 / 1 * 0,0911

<u>Scenario 1:</u> As can be understood from the formula, if some of the items were evaluated as Not Applicable, then Σ (WOj) would be smaller than 1 resulting an updated relative weight of the observed variable (UWO_{G1F5}) greater than the relative weight of the observed variable (WO_{G1F5}).

To illustrate abovementioned scenario 1: If Site evaluation of the observed variable SE_{G1F1} and SE_{G1F3} were NA; then as shown in the Table 9.4 below, Σ (WOj) becomes 0,82.

Updated relative weight of the observed variable G1F5 was calculated as:

$(UWO_{G1F5}) = [1 / \Sigma (WOj)] * WO_{G1F5}$; where j= total number of observed variables in the corresponding latent dimension .

0,1109 = 1 / 0,82 * 0,0911, showing updated relative weight of the observed variable (UWO_{G1F5} = 0,1109) was greater than the relative weight of the observed variable (WO_{G1F5} = 0,0911).

Table 9.4: The calculations of the Scenario 1

	FLj	WOj = FLj / Σ (FLj)	UWOj = [1 / Σ (WOj)] * WOj	SEj	WMDi = UWOj * SEj		SPCDi	WDi = (SPCDi) / Σ (SPCDi)	UWDi = [1 / Σ (WDi)] * WDi]	SPI = Σ(UWOj * SEj * UWDi)
Observed Variable j	**Factor loading of the observed variable j**	**Relative weight of the observed variable j**	**Updated relative weight of the observed variable j**	**Site evaluation of the observed variable j (scale: 0-100)**	**The weighted mean of the site observations of each dimension**	**Dimension i**	**Standardized path coefficient of dimension i**	**Relative weight of dimension i**	**The updated relative weight of dimension i**	**Safety Performance Index of Construction Site**
G1F5	0,71	0,0911	0,1109	90	9,9844	**G1**	0,7900	0,0568	0,0568	0,5670
G1F1	0,70	NA	NA	NA	NA					
G1F3	0,69	NA	NA	NA	NA					
G1F11	0,68	0,0873	0,1063	95	10,0938					0,5733
G1F2	0,66	0,0847	0,1031	87	8,9719					0,5095
G1F6	0,66	0,0847	0,1031	75	7,7344					0,4393
G1F8	0,65	0,0834	0,1016	60	6,0938					0,3461
G1F7	0,64	0,0822	0,1000	50	5,0000					0,2840
G1F9	0,64	0,0822	0,1000	50	5,0000					0,2840
G1F12	0,61	0,0783	0,0953	80	7,6250					0,4331
G1F4	0,58	0,0745	0,0906	75	6,7969					0,3860
G1F10	0,57	0,0732	0,0891	85	7,5703					0,4299
SUM	**7,79**	**0,82**	**1,00**		**74,87**					**4,2522**

- **Column SEj:** This column shows the site evaluations of the observed variables. Scale is between 0 and 100, where; 0= Conformity is minimum, 100= Conformity is maximum, NA: If not applicable.

- **Column WMDi:** The weighted mean of the site observations of each latent dimension was calculated by the formula below:

WMDi = Σ (UWOj * SEj)

As an example: The weighted mean of the site observations of latent dimension G1 was calculated as:

$$(\mathbf{WMD_1}) = \mathbf{UWO_1 * SE_1 + UWO_2 * SE_{2\,+} \ldots. + UWO_{12} * SE_{12}}$$

78,47 = 8,2028 + 8,9859 + 7,9718 + 8,2927 + 7,3710 + 6,3543 + 5,0064 + 4,1078 + 4,1078 + 6,2644 + 5,5841 + 6,2195.

- **Column SPCDi** demonstrated standardized path coefficient of latent dimensions.

- **Column WDi:** Relative weight of latent dimension i was calculated by the formula below:

WDi = (SPCDi) / Σ (SPCDi)

As an example: Relative weight of latent dimension 1 was calculated as:
0.0568 = 0,798 / 13,91.

- **Column UWDi:** Updated relative weight of latent dimension i was calculated by the formula below:

UWDi = [1 / Σ (WDi)] * WDi]

As an example: Updated relative weight of latent dimension 1 was calculated as:

UWD1 = [1 / Σ (WDi)] * WD1]; where i= 1,2, ..,16.

0,0568 = 1 / 1 * 0,0568.

Scenario 2: As can be understood from the formula, if latent dimension G2 was evaluated as Not Applicable (NA), then Σ (UWDi) would be smaller than 1 resulting an updated relative weight of the latent dimension (UWD1) greater than the relative weight of the latent dimension (WD1).

To illustrate abovementioned scenario 1: If Site evaluation of latent dimension G2 was NA; then as shown in the Table 9.5 below, Σ (UWDi) becomes 0,9403.

Updated relative weight of the latent dimension G1 was calculated as:

UWD1 = [1 / Σ (WDi)] * WD1]; where i= 1,2, ..,16.

0,0604 = 1 / 0,9403 * 0,0568, showing updated relative weight of latent dimension G1 (UWD1 = 0,0604) was greater than the relative weight of latent dimension G1 (UWD1 = 0,0568).

Table 9.5: The calculations of the Scenario 2

	FLj	WOj = FLj / Σ (FLj)	UWOj = [1 / Σ (WOj)] * WOj	SEj	WMDi = UWOj * SEj		SPCDi	WDi = (SPCDi) / Σ (SPCDi)	UWDi = [1 / Σ (WDi)] * WDi]	SPI = Σ(UWOj * SEj * UWDi)
Observed Variable j	**Factor loading of the observed variable j**	**Relative weight of the observed variable j**	**Updated relative weight of the observed variable j**	**Site evaluation of the observed variable j (scale: 0-100)**	**The weighted mean of the site observations of each dimension**	**Dimension i**	**Standardized path coefficient of dimension i**	**Relative weight of dimension i**	**Updated relative weight of dimension i**	**Safety Performance Index of Construction Site**
G1F5	0,71	0,0911	0,0911	90	8,2028	**G1**	0,7900	0,0568	0,0604	0,4954
G1F1	0,70	0,0899	0,0899	100	8,9859					0,5427
G1F3	0,69	0,0886	0,0886	90	7,9718					0,4815
G1F11	0,68	0,0873	0,0873	95	8,2927					0,5009
G1F2	0,66	0,0847	0,0847	87	7,3710					0,4452
G1F6	0,66	0,0847	0,0847	75	6,3543					0,3838
G1F8	0,65	0,0834	0,0834	60	5,0064					0,3024
G1F7	0,64	0,0822	0,0822	50	4,1078					0,2481
G1F9	0,64	0,0822	0,0822	50	4,1078					0,2481
G1F12	0,61	0,0783	0,0783	80	6,2644					0,3784
G1F4	0,58	0,0745	0,0745	75	5,5841					0,3373
G1F10	0,57	0,0732	0,0732	85	6,2195					0,3756
SUM	**7,79**	**1,00**	**1,00**		**78,47**					**4,7393**
G2F7	0,80	NA	NA	NA	NA	**G2**	0,8300	NA	NA	
G2F6	0,78	NA	NA	NA	NA					
G2F2	0,75	NA	NA	NA	NA					
G2F3	0,71	NA	NA	NA	NA					
G2F5	0,70	NA	NA	NA	NA					
G2F1	0,67	NA	NA	NA	NA					
G2F4	0,67	NA	NA	NA	NA					
G2F9	0,67	NA	NA	NA	NA					
G2F8	0,63	NA	NA	NA	NA					
G2F10	0,56	NA	NA	NA	NA					
SUM	**6,94**	-	-		-					-
							13,9100	**0,9403**	**1,0000**	

- The safety performance levels of latent dimensions were calculated as follows:

Safety performance level of latent dimension i = WMDi / 100= Σ (UWOj * SEj)

As an example: Safety performance level of latent dimension 1 was calculated as 78,47 / 100 = 78,47%

Safety performance levels of latent dimensions in descending order were shown in Table 9.6 and Figure 9.1 below.

Table 9.6: Safety performance levels of latent dimensions for Case study #1 (in descending order)

Latent Dimensions	**Safety Performance Level %**
G15	90,98
G14	88,19
G13	87,95
G11	87,93
G5	87,40
G6	85,46
G9	85,42
G12	82,64
G4	81,90
G10	81,15
G7	79,47
G16	79,03
G1	78,47
G2	74,55
G8	74,28
G3	69,59

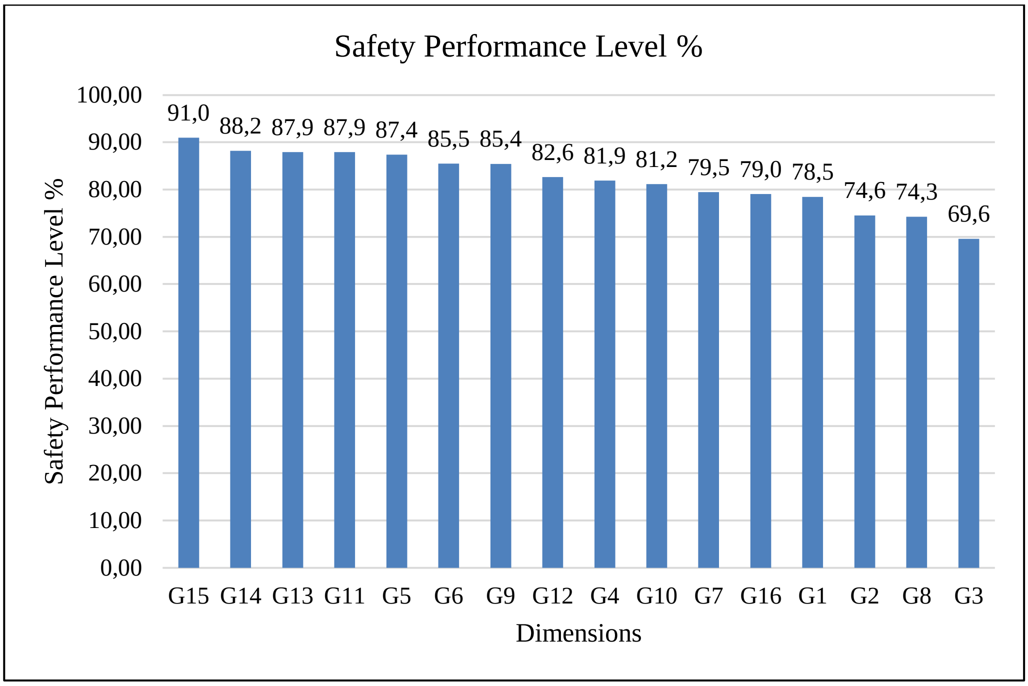


Figure 9.1: Safety performance levels of latent dimensions for Case study #1 (in descending order)

- **Column SPI:** Safety Performance Index of Construction Site was calculated by the formula below:

SPI = Σ(UWOj * SEj * UWDi); where

i= 1,2, ..,16 and

j= total number of observed variables in the corresponding latent dimension

SPI = (0,0911*90*0,0568) + …. + (0,0833*95*0,0618)

=82,1587%

The Safety Performance Index of Construction Site of Case study 1# was calculated as <u>82,1587%.</u>

9.4.2 Case study #2

In the same manner as explained in the Case study#1, the Site Safety Performance Index of Case study #2 was calculated as 74,2037%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.7 and Figure 9.2 below.

Table 9.7: Safety performance levels of latent dimensions for Case study #2 (in descending order)

Latent dimensions	Safety Performance Level %
G9	84,25
G11	83,82
G14	83,09
G6	81,73
G10	76,73
G12	76,63
G4	76,34
G8	75,91
G13	75,49
G16	72,76
G2	70,99
G5	70,05
G7	69,54
G1	60,00
G3	54,69
G15	NA

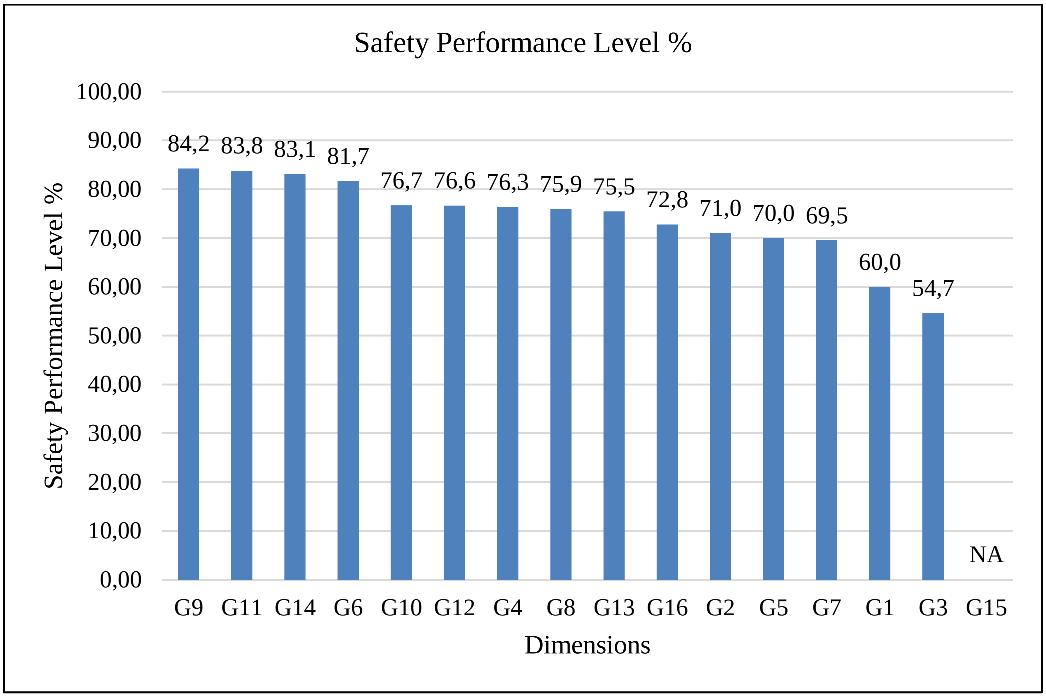


Figure 9.2: Safety performance levels of latent dimensions for Case study #2 (in descending order)

9.4.3 Case study #3

The Site Safety Performance Index of Case study #3 was calculated as 83,6432%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.8 and Figure 9.3 below.

Table 9.8: Safety performance levels of latent dimensions for Case study #3 (in descending order)

Latent dimensions	Safety Performance Level %
G6	89,83
G9	89,68
G13	88,64
G12	88,22
G4	88,08
G11	87,89
G14	87,05
G16	83,60
G8	83,52
G10	82,47
G5	81,89
G2	78,76
G7	76,79
G1	76,56
G3	70,57
G15	NA

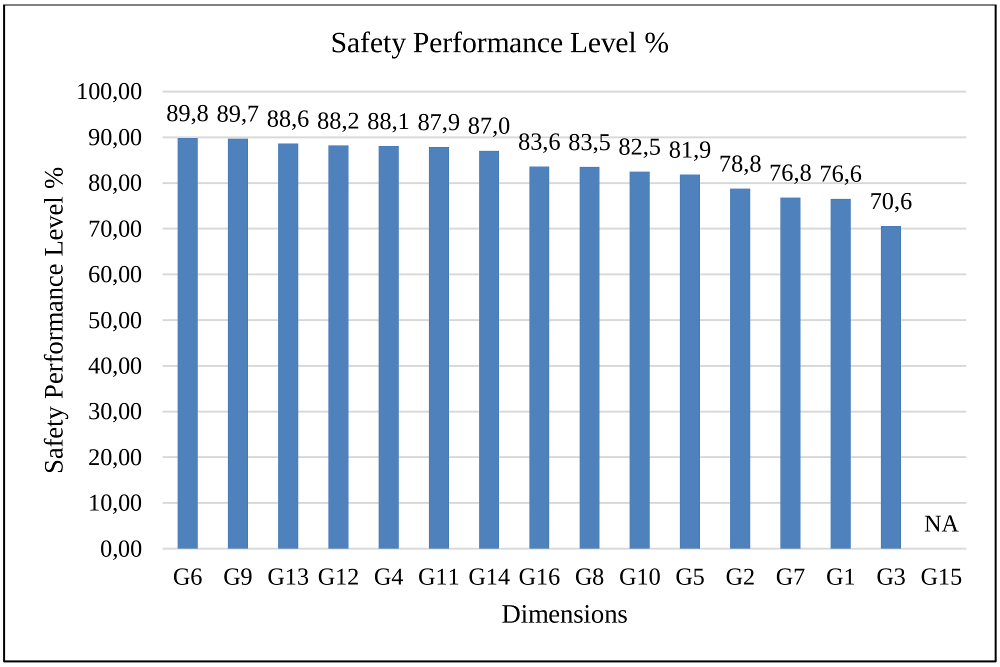


Figure 9.3: Safety performance levels of latent dimensions for Case study #3 (in descending order)

9.4.4 Case study #4

The Site Safety Performance Index of Case study #3 was calculated as 72,9721%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.9 and Figure 9.4 below.

Table 9.9: Safety performance levels of latent dimensions for Case study #4 (in descending order)

Latent dimensions	Safety Performance Level %
G6	85,41
G11	83,26
G2	79,62
G14	77,65
G7	77,13
G4	76,29
G13	74,17
G16	73,53
G5	73,09
G9	72,03
G3	71,44
G10	67,66
G12	66,75
G8	62,26
G1	57,08
G15	NA

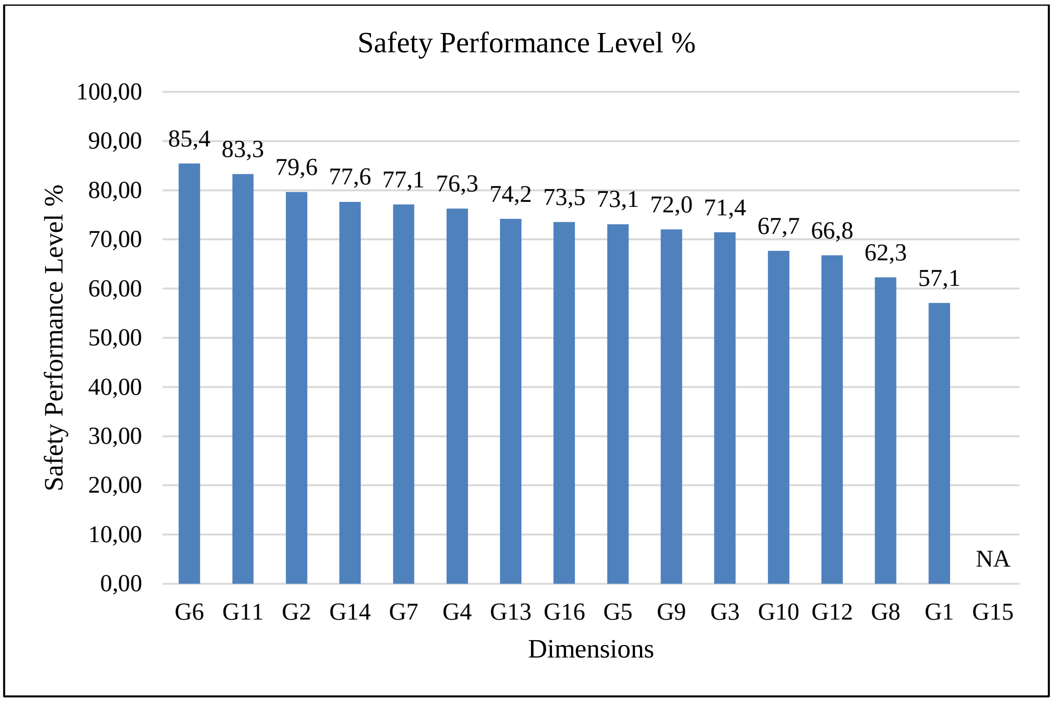


Figure 9.4: Safety performance levels of latent dimensions for Case study #4 (in descending order)

9.4.5 Case study #5

The Site Safety Performance Index of Case study #5 was calculated as 78,9790%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.10 and Figure 9.5 below.

Table 9.10: Safety performance levels of latent dimensions for Case study #5 (in descending order)

Latent dimensions	Safety Performance Level %
G11	96,19
G13	95,96
G5	90,77
G6	87,99
G2	81,30
G14	80,17
G12	80,08
G9	80,03
G7	79,92
G10	74,51
G8	74,35
G3	68,95
G4	67,29
G1	66,50
G16	65,08
G15	NA

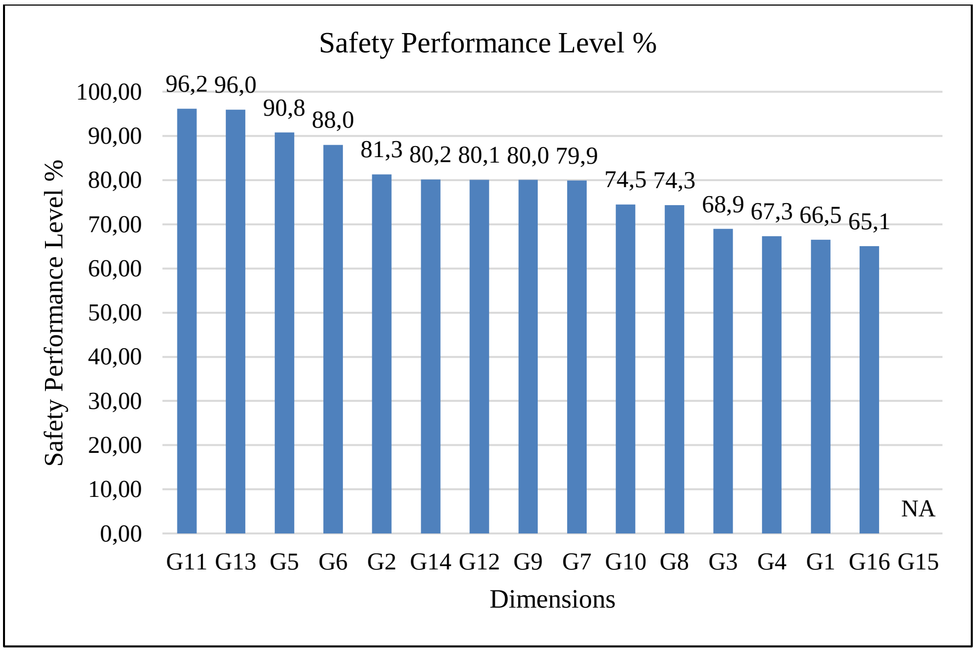


Figure 9.5: Safety performance levels of latent dimensions for Case study #5 (in descending order)

9.4.6 Case study #6

The Site Safety Performance Index of Case study #6 was calculated as 58,5732%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.11 and Figure 9.6 below.

Table 9.11: Safety performance levels of latent dimensions for Case study #6 (in descending order)

Latent dimensions	Safety Performance Level %
G4	71,46
G8	70,36
G10	69,75
G13	67,54
G9	67,40
G6	66,34
G11	65,31
G14	55,64
G7	54,13
G5	53,08
G12	52,60
G2	50,90
G3	50,37
G1	48,72
G16	47,20
G15	45,46

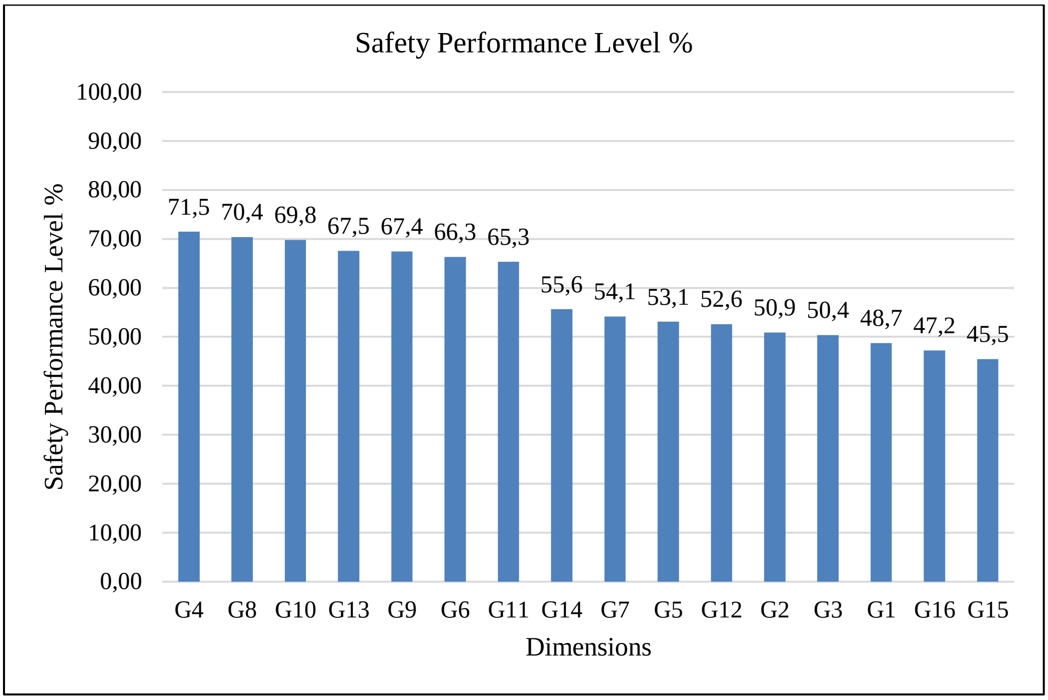


Figure 9.6: Safety performance levels of latent dimensions for Case study #6 (in descending order)

9.4.7 Case study #7

The Site Safety Performance Index of Case study #7 was calculated as 35,9261%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.12 and Figure 9.7 below.

Table 9.12: Safety performance levels of latent dimensions for Case study #7 (in descending order)

Latent dimensions	**Safety Performance Level %**
G8	56,70
G6	56,66
G13	54,45
G10	53,08
G4	52,16
G12	51,49
G16	47,79
G14	34,24
G11	31,57
G5	27,27
G9	26,60
G3	25,04
G1	21,27
G15	12,22
G2	9,83
G7	8,48

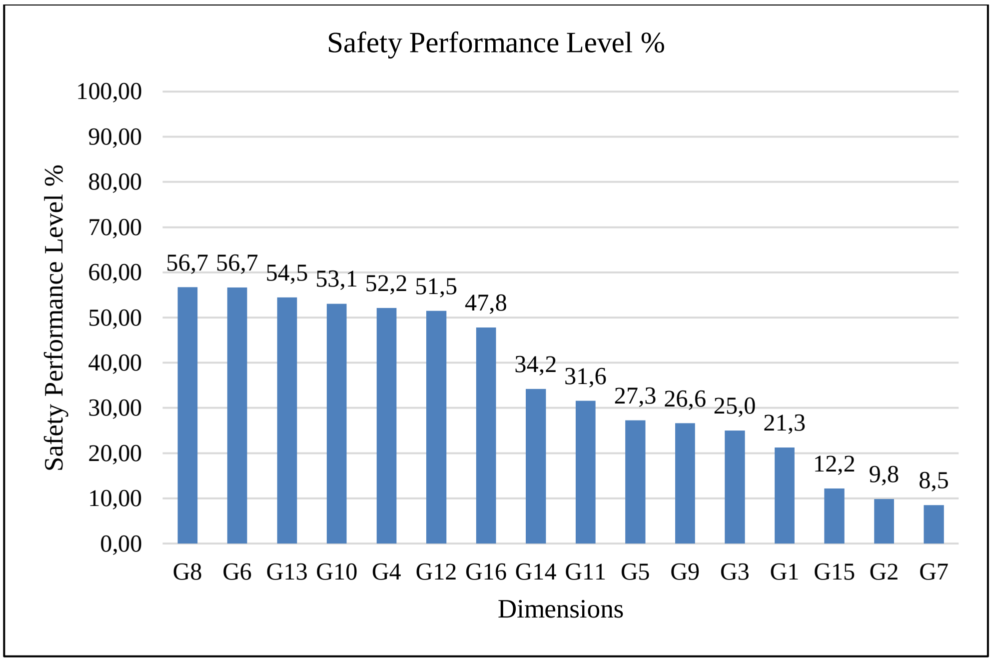


Figure 9.7: Safety performance levels of latent dimensions for Case study #7 (in descending order)

9.4.8 Case study #8

The Site Safety Performance Index of Case study #8 was calculated as 63,4396%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.13 and Figure 9.8 below.

Table 9.13: Safety performance levels of latent dimensions for Case study #8 (in descending order)

Latent dimensions	Safety Performance Level %
G7	82,90
G4	77,96
G5	72,72
G6	70,95
G3	67,68
G11	63,22
G14	62,77
G13	62,55
G9	61,74
G8	59,72
G15	59,50
G1	59,31
G16	57,50
G12	54,78
G2	51,77
G10	51,63

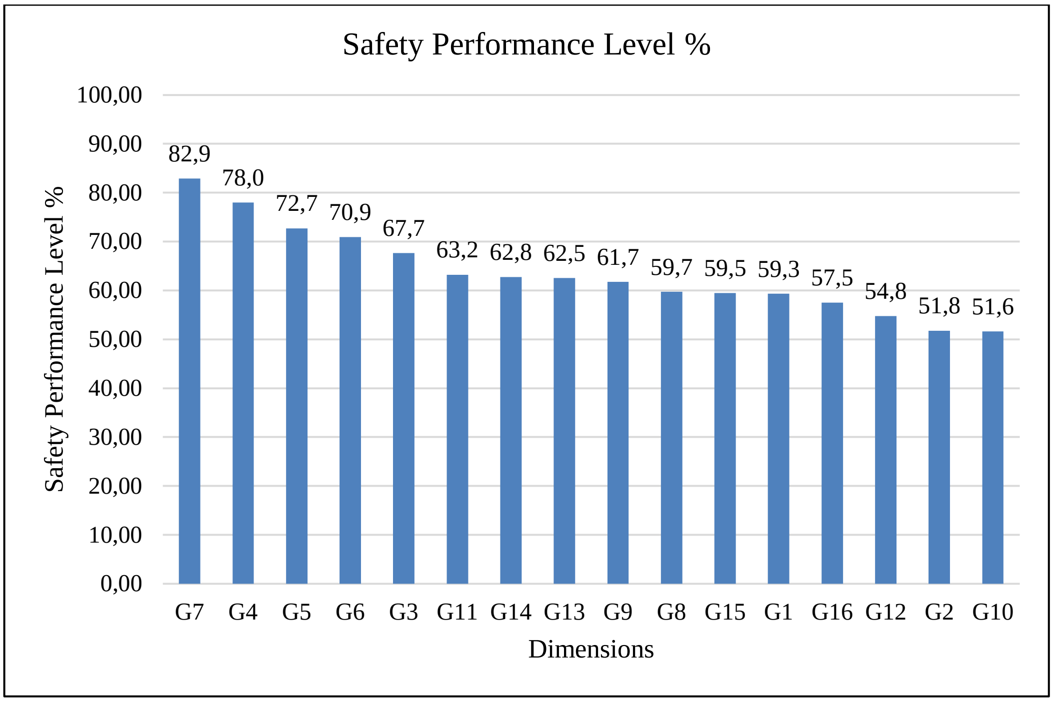


Figure 9.8: Safety performance levels of latent dimensions for Case study #8 (in descending order)

9.4.9 Case study #9

The Site Safety Performance Index of Case study #9 was calculated as 74,5183%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.14 and Figure 9.9 below.

Table 9.14: Safety performance levels of latent dimensions for Case study #9 (in descending order)

Latent dimensions	Safety Performance Level %
G14	86,22
G6	83,71
G15	81,11
G5	80,11
G1	79,72
G16	78,66
G10	78,22
G13	76,39
G3	76,16
G12	74,10
G11	73,80
G8	68,41
G2	67,65
G9	65,57
G4	62,78
G7	59,11

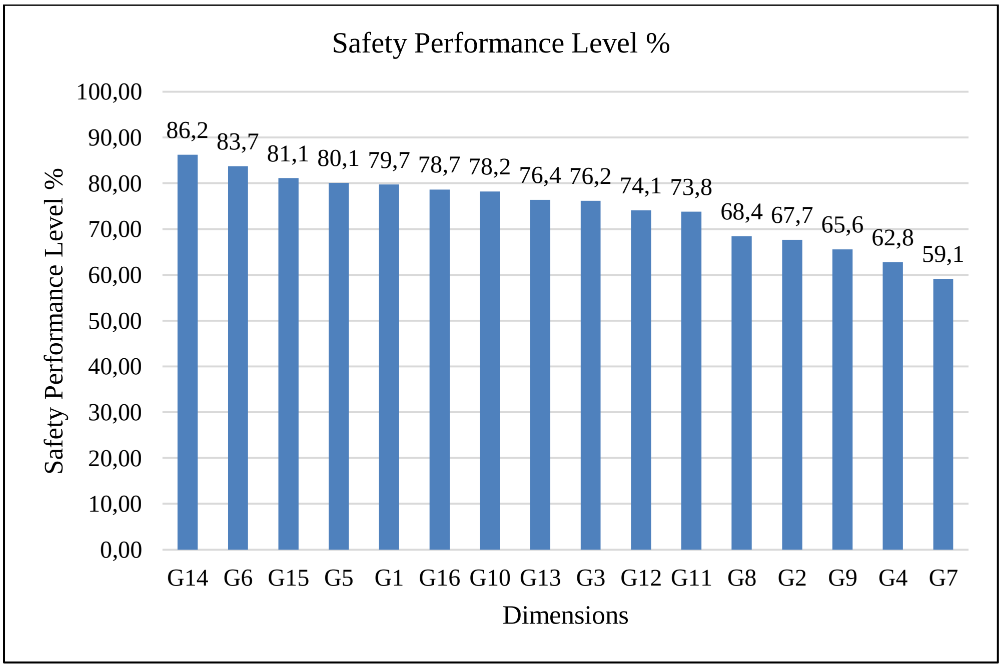


Figure 9.9: Safety performance levels of latent dimensions for Case study #9 (in descending order)

9.4.10 Case study #10

The Site Safety Performance Index of Case study #10 was calculated as 73,1295%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.15 and Figure 9.10 below.

Table 9.15: Safety performance levels of latent dimensions for Case study #10 (in descending order)

Latent dimensions	Safety Performance Level
G11	86,07
G13	82,94
G16	81,24
G7	80,68
G15	80,13
G9	79,22
G6	77,67
G12	76,04
G1	71,89
G14	70,96
G10	68,93
G2	68,25
G3	65,39
G8	64,37
G5	59,87
G4	59,83

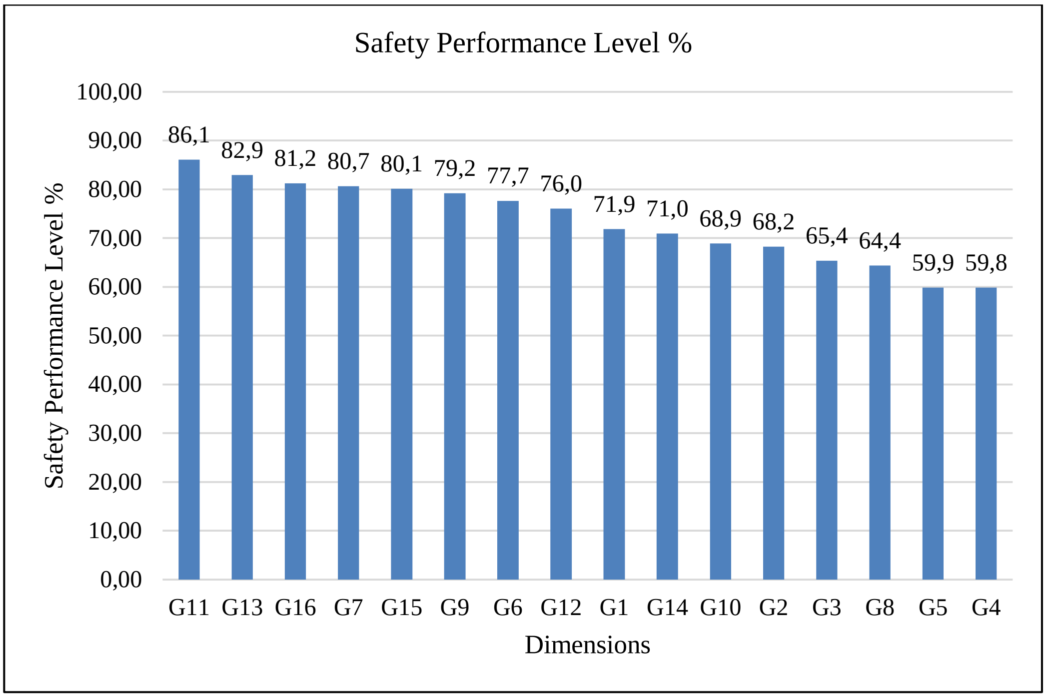


Figure 9.10: Safety performance levels of latent dimensions for Case study #10 (in descending order)

9.4.11 Case study #11

The Site Safety Performance Index of Case study #11 was calculated as 91,5785%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.16 and Figure 9.11 below.

Table 9.16: Safety performance levels of latent dimensions for Case study #11 (in descending order)

Dimension	Safety Performance Level
G7	100,00
G13	100,00
G16	96,00
G10	95,54
G11	94,96
G9	93,72
G3	93,42
G12	92,33
G6	92,22
G4	91,80
G14	91,01
G8	86,72
G2	83,85
G1	81,47
G5	79,94
G15	NA

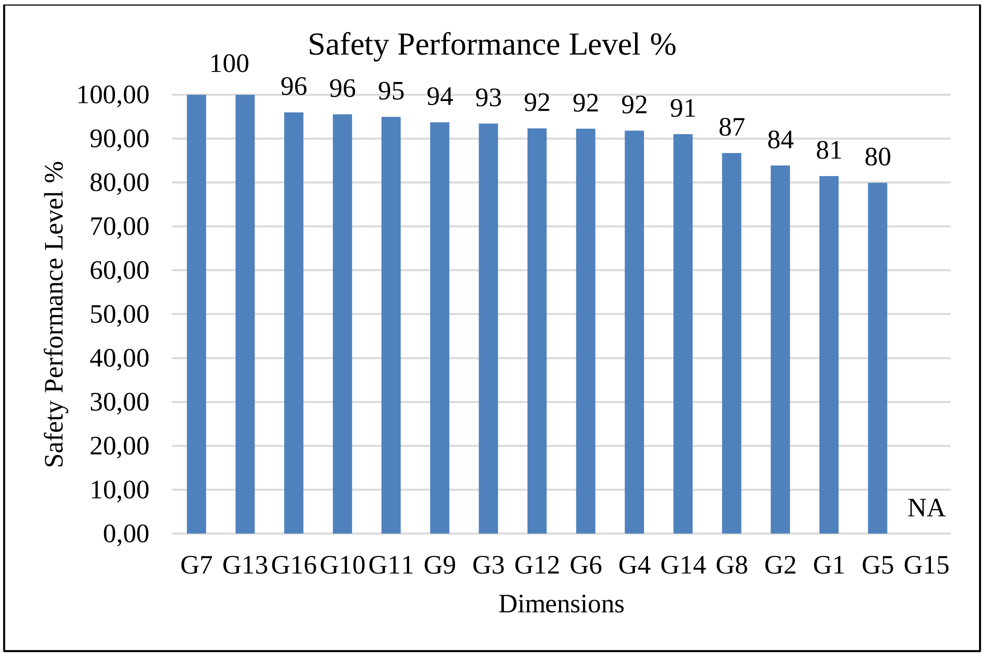


Figure 9.11: Safety performance levels of latent dimensions for Case study #11 (in descending order)

9.5 Benchmarking of construction sites of case studies #1 to #11 according to safety performance

The Site Safety Performance Indices of 11 Case studies were calculated and shown in Table 9.17 and Figure 9.12 below in descending order.

Table 9.17: Calculated safety performance indices for Case studies #1 to #11 (in descending order)

Case study #	**Site Safety Performance Index %**
Case study #11	91,5785
Case study #3	83,6432
Case study #1	82,1587
Case study #5	78,9790
Case study #9	74,5183
Case study #2	74,2037
Case study #10	73,1295
Case study #4	72,9721
Case study #8	63,4396
Case study #6	58,5732
Case study #7	35,9261

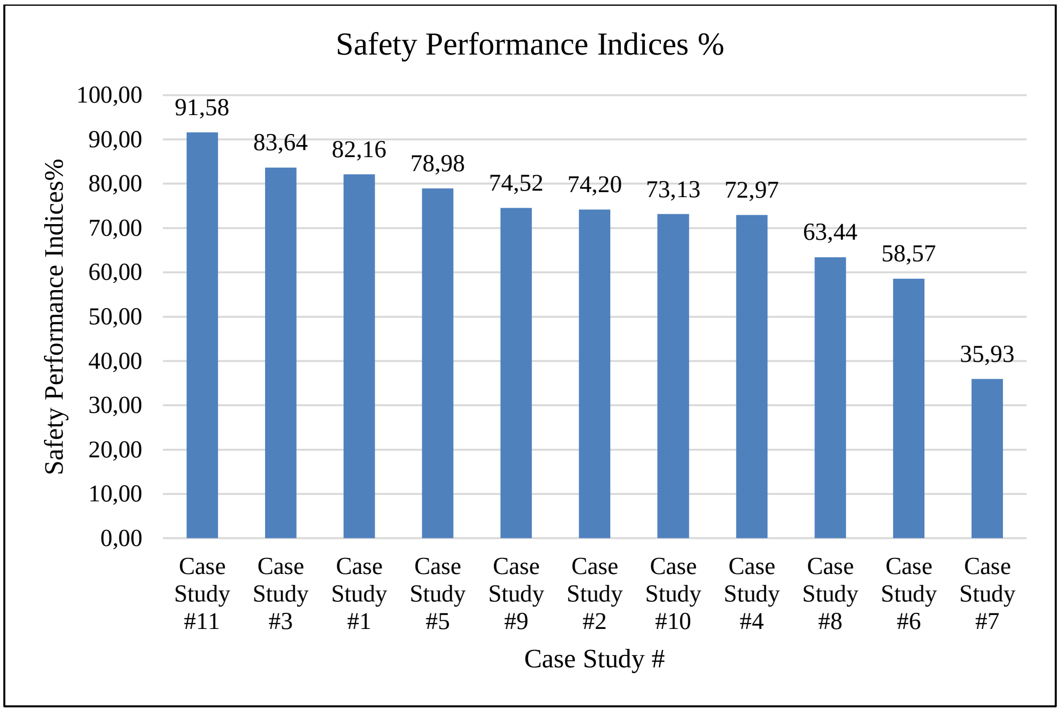


Figure 9.12: Calculated safety performance indices for Case studies #1 to #11 (in descending order)

9.6 Proposal of a short (simple) model (48 observed variables in 16 latent dimensions) as an alternative to the full model (168 observed variables in 16 latent dimensions)

In the previous parts, to assess the safety performance of 11 different international construction sites, investigations were made by safety professionals of construction companies. The evaluation forms including the full list of 168 observed variables in 16 latent dimensions of safety performance were filled at the construction sites by safety engineers of the companies working for the Case study projects. The Site Safety Performance Indices of 11 Case studies were calculated accordingly.

In this part, since it is quite harder and more time consuming for safety engineers to evaluate 168 observed variables in 16 latent dimensions, a relatively short and simple model was proposed consisting of the top three most important observed variables taking into account of their factor loadings calculated previously for each 16 latent dimensions affecting safety performance of construction sites.

This short model consisted of 48 observed variables in 16 latent dimensions.

9.6.1 Case study #1 (short model)

Proposed short model was implemented to the first case study project and the Site Safety Performance Index of Case study #1 was calculated as 84,3945%. Detailed information regarding the calculation of the Site Safety Performance Index was given in Appendix I:

Explanations of the formulas in the Appendix I were listed as follows:

- **Column FLj:** In this table, observed variables were listed in the descending order with respect to their factor loadings (FL_j) ; where j= 1, 2, 3. (In each latent dimension, only top three observed variables with respect to their factor loadings in descending order.)

- **Column WOj:** Relative weight of the observed variable j was calculated by the formula below:

  WOj = FLj / Σ (FLj); where FLj = Factor loading of the observed variable $_{\mathbf{j}}$**.**

  As an example: Relative weight of the observed variable G1F5 was calculated as:
  (WO_{G1F5}) = (FL_{G1F5}) / Σ (FLj; where j= total number of observed variables in the corresponding latent dimension.

0,3381 = 0,71 / 2,10.

- **Column UWOj:** Updated relative weight of the observed variable j was calculated by the formula below:

UWOj = [1 / Σ (WOj)] * WOj.

As an example: Updated relative weight of the observed variable G1F5 was calculated as:
(UWO_{G1F5}) = [1 / Σ (WOj)] * WO_{G1F5}; where j= total number of observed variables in the corresponding latent dimension
0,3381 = 1 / 1 * 0,3381.

Scenario 1: As can be understood from the formula, if some of the items were evaluated as Not Applicable, then Σ (WOj) would be smaller than 1 resulting an updated relative weight of the observed variable (UWO_{G1F5}) greater than the relative weight of the observed variable (WO_{G1F5}).

To illustrate abovementioned scenario 1: If Site evaluation of the observed variable SE_{G1F1} was NA; then as shown in the Table 9.17 below, Σ (WOj) becomes 0,67.

Updated relative weight of the observed variable G1F5 was calculated as:

(UWO_{G1F5}) = [1 / Σ (WOj)] * WO_{G1F5}; where j= total number of observed variables in the corresponding latent dimension.
0,5071 = 1 / 0,67 * 0,3381, showing updated relative weight of the observed variable (UWO_{G1F5} = 0,5071) was greater than the relative weight of the observed variable (WO_{G1F5} = 0,3381).

Table 9.18: The calculations of the Scenario 1 for short model

	FLj	WOj = FLj / Σ (FLj)	UWOj = [1 / Σ (WOj)] * WOj	SEj	WMDi = Σ(UWOj * SEj)		SPCDi	WDi = (SPCDi) / Σ (SPCDi)	UWDi = [1 / Σ (WDi)] * WDi]	SPI = Σ(UWOj * SEj * UWDi)
Observed Variable j	**Factor loading of the observed variable j**	**Relative weight of the observed variable j**	**Updated relative weight of the observed variable j**	**Site evaluation of the observed variable j (scale: 0-100)**	**The weighted mean of the site observations of each dimension**	**Dimension i**	**Standardized path coefficient of dimension i**	**Relative weight of dimension i**	**Updated relative weight of dimension i**	**Safety Performance Index of Construction Site**
G1F5	0,71	0,3381	0,5071	75	38,0357	**G1**	0,7900	0,0568	0,0609	2,3150
G1F1	0,70	NA	NA	NA	NA					
G1F3	0,69	0,3286	0,4929	55	27,1071					1,6498
SUM	**2,10**	**0,67**	**1,00**		**65,14**					**3,9648**

- **Column SEj:** This column shows the site evaluations of the observed variables. Scale is between 0 and 100, where; 0= Conformity is minimum, 100= Conformity is maximum, NA: If not applicable.

- **Column WMDi:** The weighted mean of the site observations of each latent dimension was calculated by the formula below:

  WMDi = Σ (UWOj * SEj)

  As an example: The weighted mean of the site observations of latent dimension 1 was calculated as:
  (WMD_1) = $UWO_1 * SE_1 + UWO_2 * SE_2 + UWO_3 * SE_3$
  93,33 = 30,4286 + 33,3333 + 29,5714

- **Column SPCDi** demonstrated standardized path coefficient of latent dimensions.

- **Column WDi:** Relative weight of latent dimension i was calculated by the formula below:

  WDi = (SPCDi) / Σ (SPCDi)

  As an example: Relative weight of latent dimension 1 was calculated as:
  0.0568 = 0,798 / 13,91.

- **Column UWDi:** Updated relative weight of latent dimension i was calculated by the formula below:

  UWDi = [1 / Σ (WDi)] * WDi]

As an example: Updated relative weight of latent dimension 1 was calculated as:

UWD1 = [1 / Σ (WDi)] * WD1]; where i= 1, 2, .., 16.

0,0568 = 1 / 1 * 0,0568

Scenario 2: As can be understood from the formula, if latent dimension 2 was evaluated as Not Applicable (NA), then Σ (UWDi) would be smaller than 1 resulting an updated relative weight of the latent dimension (UWD1) greater than the relative weight of the latent dimension (WD1).

To illustrate abovementioned scenario 2: If Site evaluation of latent dimension 2 was NA; then as shown in the Table 9.18 below, Σ (UWDi) becomes 0,9403.

Updated relative weight of the latent dimension 1 was calculated as:

UWD1 = [1 / Σ (WDi)] * WD1]; where i= 1,2, ..,16.

0,0604 = 1 / 0,9403 * 0,0568, showing updated relative weight of latent dimension 1 (UWD1 = 0,0604) was greater than the relative weight of latent dimension 1 (UWD1 = 0,0568).

Table 9.19: The calculations of the Scenario 2 for short model

	FLj	WOj = FLj / Σ (FLj)	UWOj = [1 / Σ (WOj)] * WOj	SEj	WMDi = Σ(UWOj * SEj)		SPCDi	WDi = (SPCDi) / Σ (SPCDi)	UWDi = [1 / Σ (WDi)] * WDi]	SPI = Σ(UWOj * SEj * UWDi)
Observed Variable j	**Factor loading of the observed variable j**	**Relative weight of the observed variable j**	**Updated relative weight of the observed variable j**	**Site evaluation of the observed variable j (scale: 0-100)**	**The weighted mean of the site observations of each dimension**	**Dimension i**	**Standardized path coefficient of dimension i**	**Relative weight of dimension i**	**Updated relative weight of dimension i**	**Safety Performance Index of Construction Site**
G1F5	0,71	0,3381	0,3381	90	30,4286	**G1**	0,7900	0,0568	0,0604	1,8378
G1F1	0,70	0,3333	0,3333	100	33,3333					2,0133
G1F3	0,69	0,3286	0,3286	90	29,5714					1,7860
SUM	**2,10**	**1,00**	**1,00**		**93,33**					**5,6371**
G2F7	0,80	NA	NA	NA	NA	**G2**	0,8300	NA	NA	
G2F6	0,78	NA	NA	NA	NA					
G2F2	0,75	NA	NA	NA	NA					
SUM	**2,33**	-	-		-					-
							13,9100	**0,9403**	**1,0000**	

- For Short Model, the safety performance levels of latent dimensions were calculated as follows:

  Safety performance level of latent dimension i = WMDi / 100= Σ (UWOj * SEj)

  As an example: Safety performance level of latent dimension 1 was calculated as 93,33 / 100 = 93,33%.

  Safety performance levels of latent dimensions in descending order were shown in Table 9.20 and Figure 9.13 below.

Table 9.20: Safety performance levels of latent dimensions for Case study #1 for Short Model (in descending order)

Latent dimensions	**Safety Performance Level %**
G14	95,10
G1	93,33
G13	90,00
G15	90,00
G10	89,39
G12	88,24
G6	86,64
G11	86,59
G7	85,04
G4	84,98
G9	83,40
G8	83,35
G2	83,26
G5	78,61
G16	66,70
G3	65,07

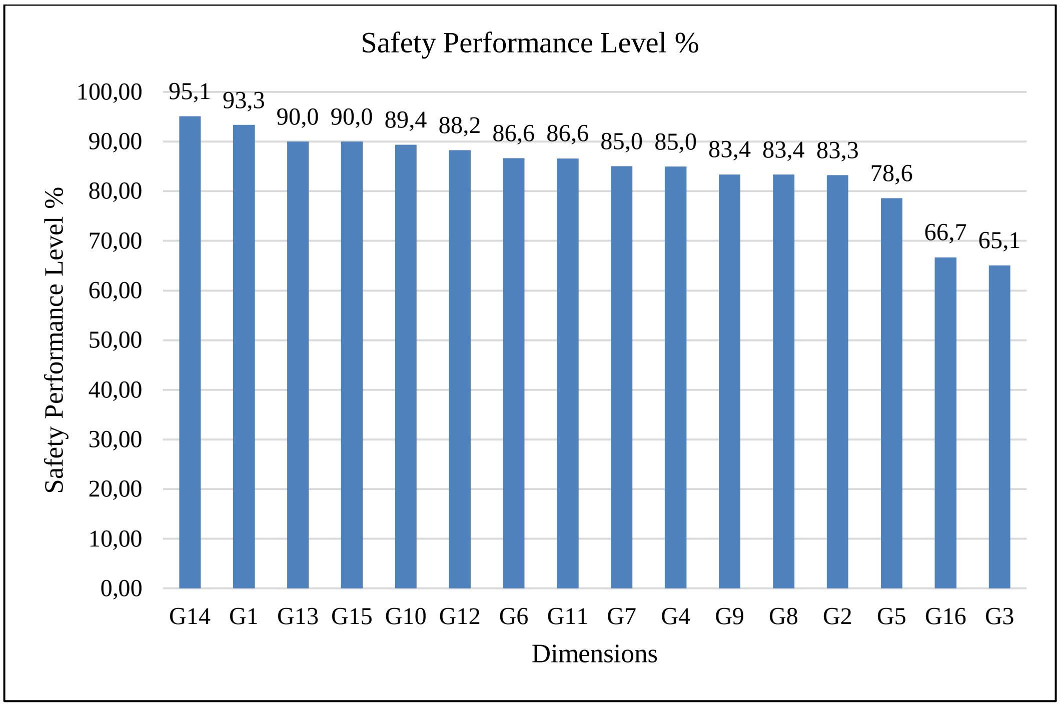


Figure 9.13: Safety performance levels of latent dimensions for Case study #1 (in descending order)

- **Column SPI:** Safety Performance Index of Construction Site was calculated by the formula below:

SPI $= \Sigma(UWOj * SEj * UWDi)$;where

i= 1,2, ..,16 and

j= 1, 2, 3.

SPI =(0,3381*90*0,0568) + …. + (0,3319*75*0,0618)

=84,3945%

The Safety Performance Index of Construction Site of Case study 1# was calculated as 84,3945%.

9.6.2 Case study #2 (short model)

Proposed short model was implemented to the second Case study project and the Site Safety Performance Index of Case study #2 was calculated as 76,4155%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.21 and Figure 9.14 below.

Table 9.21: Safety performance levels of latent dimensions for Case study #2 for Short Model (in descending order)

Latent dimensions	**Safety Performance Level %**
G12	89,88
G2	88,45
G10	84,81
G8	83,42
G14	80,49
G9	78,19
G4	78,16
G11	76,81
G6	76,56
G13	75,02
G1	73,43
G16	73,32
G5	66,80
G7	61,74
G3	56,46
G15	NA

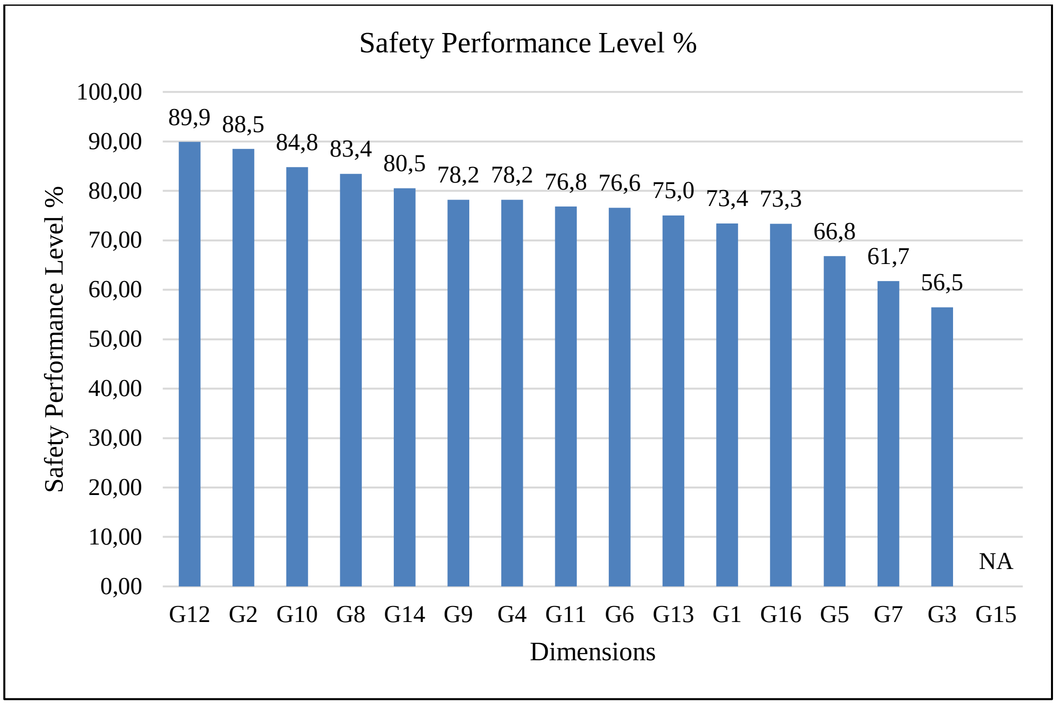


Figure 9.14: Safety performance levels of latent dimensions for Case study #2 (in descending order)

9.6.3 Case study #3 (short model)

Proposed short model was implemented to the second Case study project and the Site Safety Performance Index of Case study #3 was calculated as 85,3074%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.22 and Figure 9.15 below.

Table 9.22: Safety performance levels of latent dimensions for Case study #3 for Short Model (in descending order)

Latent dimensions	**Safety Performance Level %**
G10	96,65
G12	93,30
G9	91,73
G14	91,64
G6	89,88
G4	88,29
G13	86,70
G8	85,13
G16	84,98
G1	84,11
G11	83,26
G2	82,79
G3	74,98
G5	73,57
G7	68,40
G15	NA

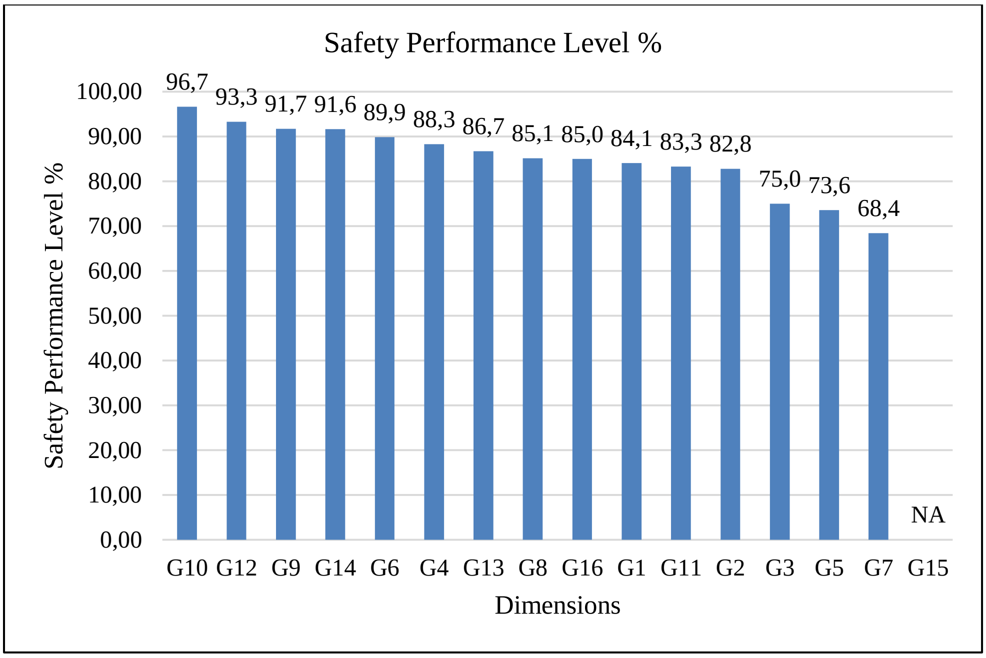


Figure 9.15: Safety performance levels of latent dimensions for Case study #3 (in descending order)

9.6.4 Case study #4 (short model)

Proposed short model was implemented to the second Case study project and the Site Safety Performance Index of Case study #4 was calculated as 75,4704%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.23 and Figure 9.16 below.

Table 9.23: Safety performance levels of latent dimensions for Case study #4 for Short Model (in descending order)

Latent dimensions	Safety Performance Level %
G6	96,64
G2	92,06
G14	86,84
G11	86,56
G10	81,69
G5	80,22
G7	76,64
G4	75,20
G3	73,43
G16	71,58
G13	66,68
G12	65,22
G9	63,46
G1	63,43
G8	56,52
G15	NA

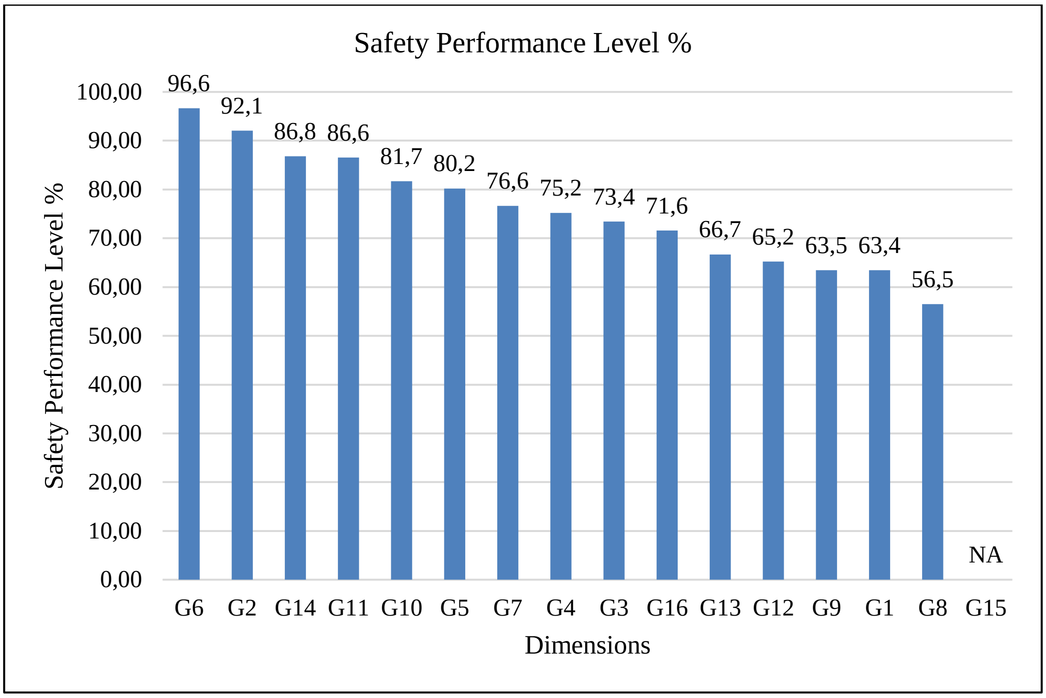


Figure 9.16: Safety performance levels of latent dimensions for Case study #4 (in descending order)

9.6.5 Case study #5 (short model)

Proposed short model was implemented to the second Case study project and the Site Safety Performance Index of Case study #5 was calculated as 82,2731%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.24 and Figure 9.17 below.

Table 9.24: Safety performance levels of latent dimensions for Case study #5 for Short Model (in descending order)

Latent dimensions	Safety Performance Level %
G11	96,70
G13	96,68
G12	93,30
G6	91,66
G2	88,50
G5	87,01
G7	85,04
G9	83,42
G3	79,43
G14	78,83
G10	78,43
G1	78,40
G4	74,50
G16	66,64
G8	60,13
G15	NA

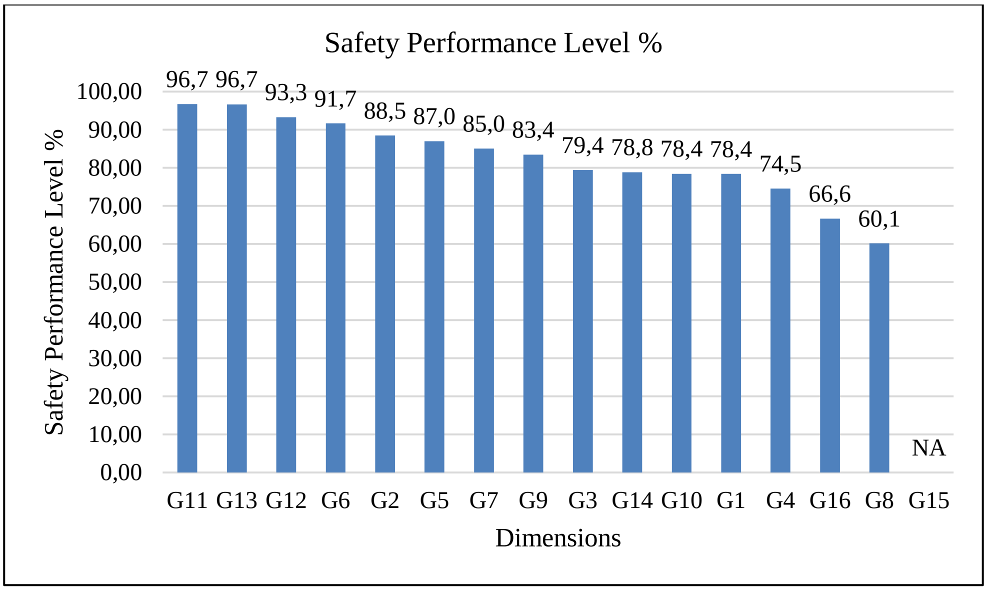


Figure 9.17: Safety performance levels of latent dimensions for Case study #5 (in descending order)

9.6.6 Case study #6 (short model)

Proposed short model was implemented to the second Case study project and the Site Safety Performance Index of Case study #6 was calculated as 60,9029%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.25 and Figure 9.18 below.

Table 9.25: Safety performance levels of latent dimensions for Case study #6 for Short Model (in descending order)

Latent dimensions	Safety Performance Level %
G4	86,75
G10	79,86
G13	66,70
G11	66,59
G14	65,43
G9	64,98
G8	64,94
G3	58,48
G6	58,16
G12	56,60
G7	53,20
G15	53,05
G5	52,16
G16	51,68
G2	49,79
G1	41,79

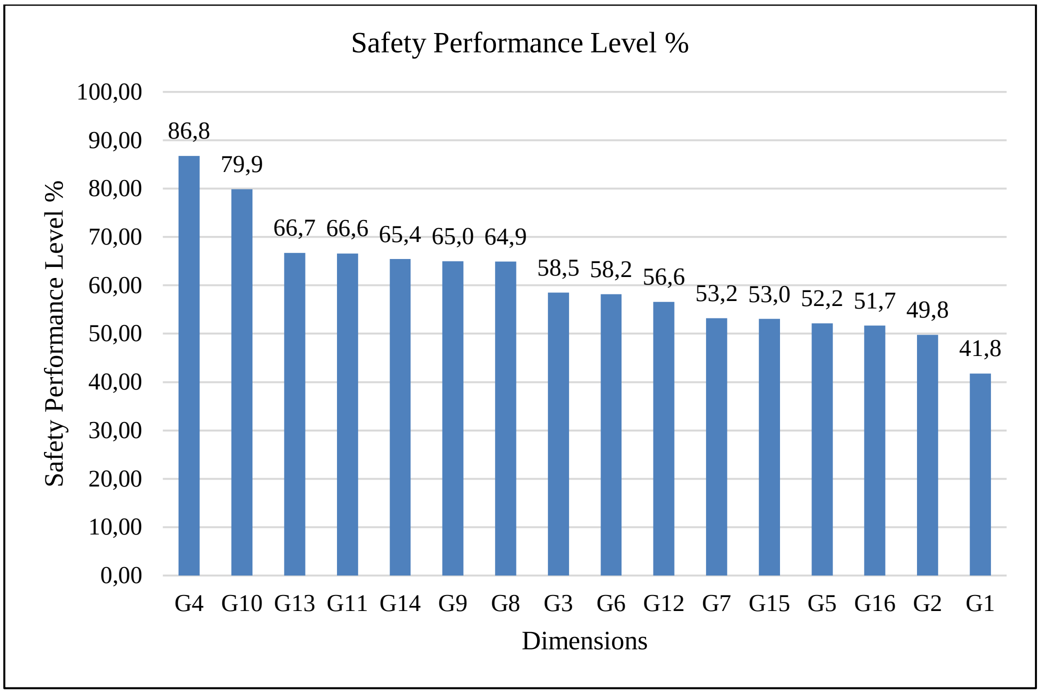


Figure 9.18: Safety performance levels of latent dimensions for Case study #6 (in descending order)

9.6.7 Case study #7 (short model)

Proposed short model was implemented to the second Case study project and the Site Safety Performance Index of Case study #7 was calculated as 39,0397%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.26 and Figure 9.19 below.

Table 9.26: Safety performance levels of latent dimensions for Case study #7 for Short Model (in descending order)

Latent dimensions	Safety Performance Level %
G4	69,61
G8	60,00
G6	59,84
G10	56,69
G14	53,89
G12	53,36
G13	53,36
G11	50,00
G16	43,45
G3	36,46
G9	26,46
G5	24,07
G15	14,94
G1	13,14
G7	3,32
G2	0,00

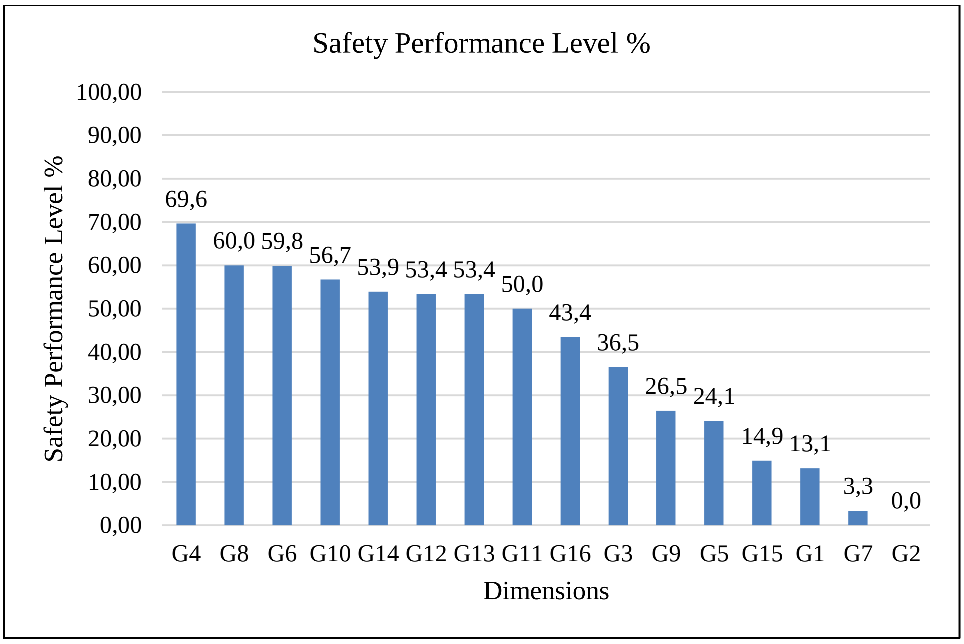


Figure 9.19: Safety performance levels of latent dimensions for Case study #7 (in descending order)

9.6.8 Case study #8 (short model)

Proposed short model was implemented to the second Case study project and the Site Safety Performance Index of Case study #8 was calculated as 64,5250%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.27 and Figure 9.20 below.

Table 9.27: Safety performance levels of latent dimensions for Case study #8 for Short Model (in descending order)

Latent dimensions	Safety Performance Level %
G7	86,70
G14	77,05
G4	75,11
G15	71,67
G13	70,04
G6	69,76
G8	68,10
G3	65,02
G2	61,72
G9	60,08
G16	59,96
G5	58,70
G11	53,41
G10	53,39
G1	49,90
G12	48,62

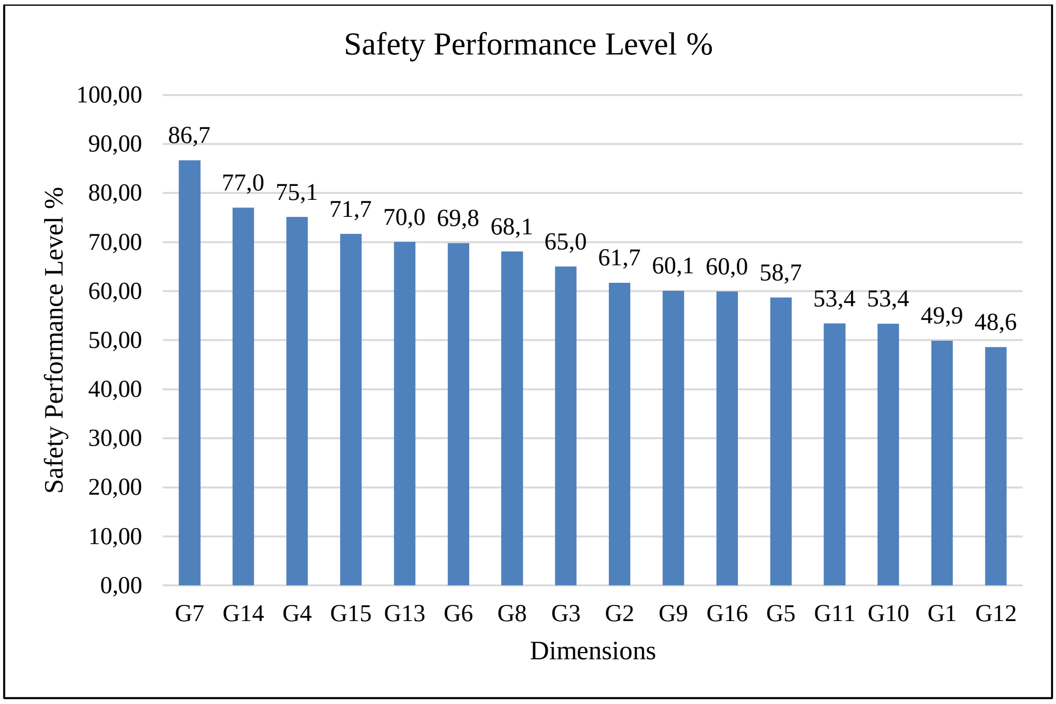


Figure 9.20: Safety performance levels of latent dimensions for Case study #8 (in descending order)

9.6.9 Case study #9 (short model)

Proposed short model was implemented to the second Case study project and the Site Safety Performance Index of Case study #9 was calculated as 76,4673%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.28 and Figure 9.21 below.

Table 9.28: Safety performance levels of latent dimensions for Case study #9 for Short Model (in descending order)

Latent dimensions	Safety Performance Level %
G14	96,74
G15	90,21
G5	83,42
G3	83,25
G6	81,58
G10	78,43
G13	76,66
G11	74,96
G1	74,95
G8	74,94
G12	73,38
G16	71,70
G9	71,69
G4	67,92
G2	66,74
G7	53,32

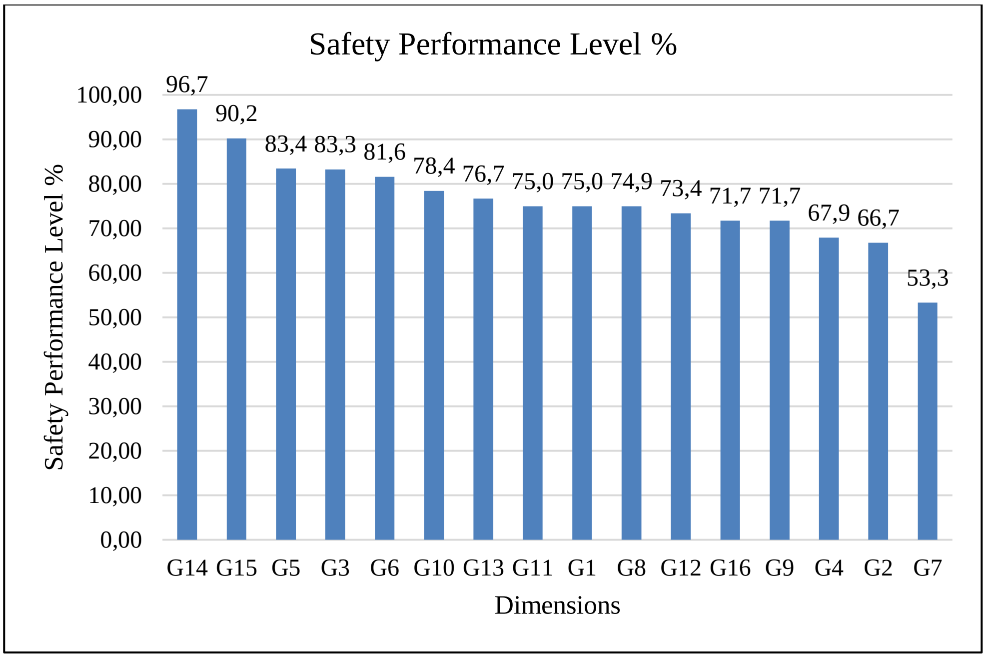


Figure 9.21: Safety performance levels of latent dimensions for Case study #9 (in descending order)

9.6.10 Case study #10 (short model)

Proposed short model was implemented to the second Case study project and the Site Safety Performance Index of Case study #10 was calculated as 75,0648%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.29 and Figure 9.22 below.

Table 9.29: Safety performance levels of latent dimensions for Case study #10 for Short Model (in descending order)

Latent dimension	Safety Performance Level %
G15	85,06
G13	84,98
G14	83,48
G9	83,46
G7	83,30
G11	81,59
G16	80,00
G6	76,60
G1	73,40
G8	71,71
G3	71,70
G2	70,04
G12	68,56
G4	68,20
G10	63,37
G5	56,58

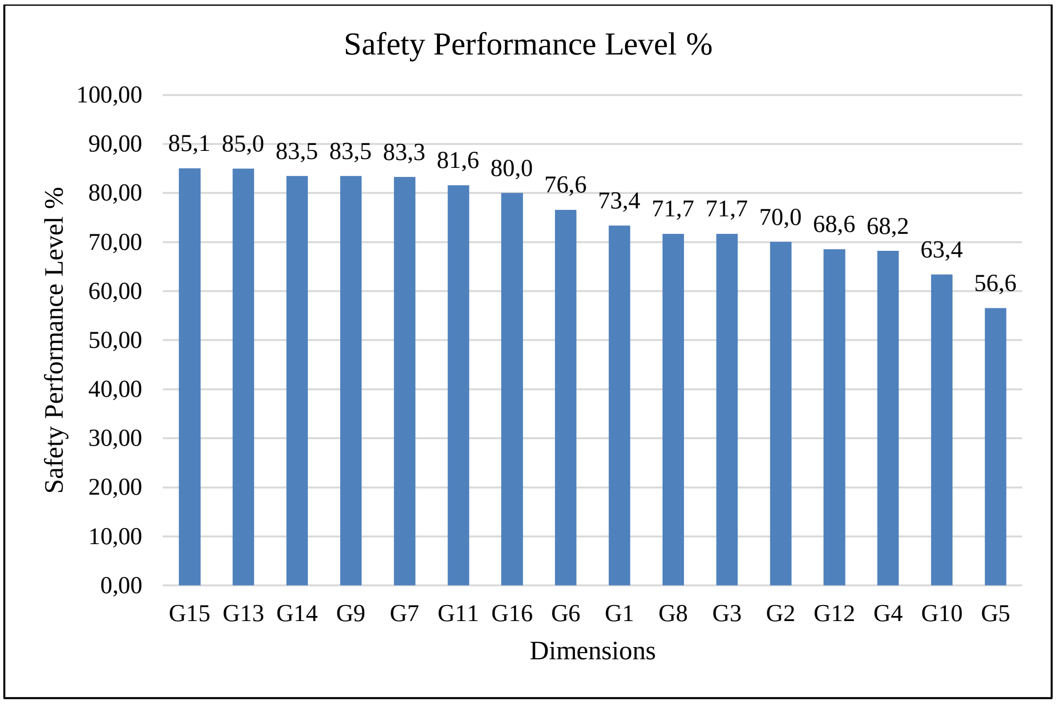


Figure 9.22: Safety performance levels of latent dimensions for Case study #10 (in descending order)

9.6.11 Case study #11 (short model)

Proposed short model was implemented to the second Case study project and the Site Safety Performance Index of Case study #11 was calculated as 91,2943%.

Safety performance levels of latent dimensions in descending order were shown in Table 9.30 and Figure 9.23 below.

Table 9.30: Safety performance levels of latent dimensions for Case study #11 for Short Model (in descending order)

Dimension	Safety Performance Level %
G13	100,00
G7	100,00
G10	100,00
G11	96,59
G16	93,36
G6	93,28
G3	93,27
G9	93,25
G4	93,07
G11	91,29
G8	90,00
G14	86,97
G2	86,78
G12	83,24
G1	80,00
G5	79,78
G15	NA

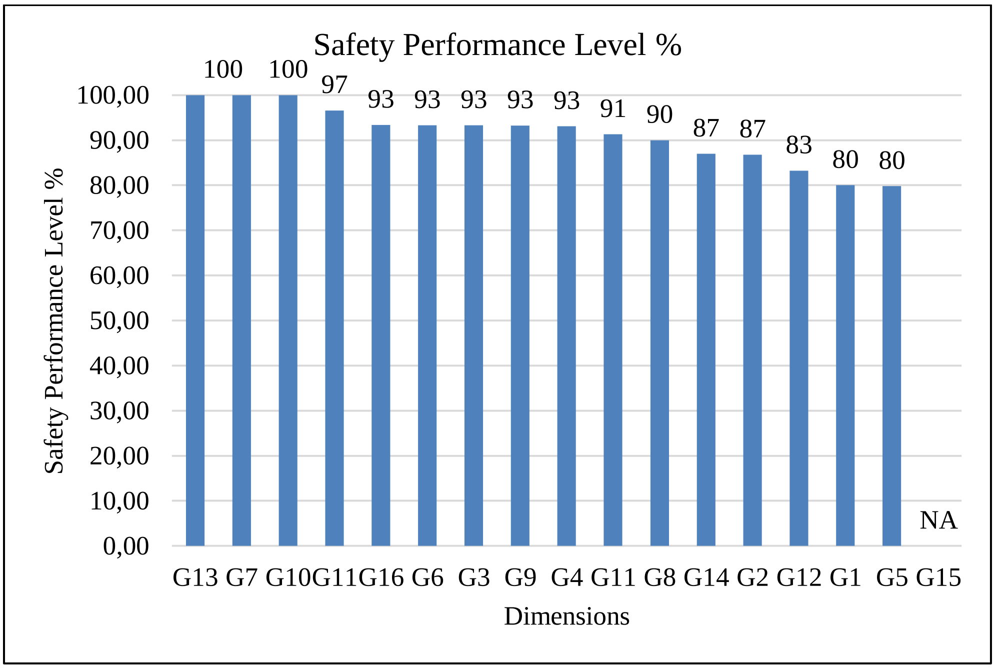


Figure 9.23: Safety performance levels of latent dimensions for Case study #11 (in descending order)

9.7 Discussion of results (comparison of the results of short (simple) model and the full model)

In this part, results of the short (simple) model and the full model were compared for Case studies #1 to #11. To illustrate: The Site Safety Performance Index of Case study #1 for short model was calculated as 84,3945%. As known, it was found to be 82,1587% in the full model.

Deviation of the result of the short model from the result of the full model was calculated by the following formula:

Deviation= (Short Model Result – Full Model result) / Full Model result
Deviation for $_{\text{Case study \#1}}$ = (84,3945% - 82,1587%) / 82,1587%)
Deviation for $_{\text{Case study \#1}}$ = 2,72%

Results of the comparison between short model and full model was shown in Table 9.31 and Figure 9.24 below.

Table 9.31: The results of comparison between short model and full model

Case study #	**Full Model Result %**	**Short Model Result %**	**Deviation %**
Case study #1	82,1587	84,3945	2,72
Case study #2	74,2037	76,4155	2,98
Case study #3	83,6432	85,3074	1,99
Case study #4	72,9721	75,4704	3,42
Case study #5	78,9790	82,2731	4,17
Case study #6	58,5732	60,9029	3,98
Case study #7	35,9261	39,0397	8,67
Case study #8	63,4396	64,5250	1,71
Case study #9	74,5183	76,4673	2,62
Case study #10	73,1295	75,0648	2,65
Case study #11	91,5785	91,2943	-0,31

Figure 9.24: Demonstration of the results of comparison between short model and full model

The average deviation of the short model results from full model result was calculated as + 3,14%. Since the average deviation was smaller than 5%, it is quite reasonable to utilize the proposed short model taking into account its simplicity, fastness and reasonable accuracy.

9.8 Chapter summary

Structural equation modeling was utilized to achieve objectives of the current thesis proposal to study the relationships between determinants of safety performance, and to develop and validate a multidimensional safety performance model.

SEM was selected as an analysis and testing tool for the current study because of its unique features over other multivariate techniques (Biddle and Marlin 1987; Myers 1990; Greene 1990; Crowley and Fan 1997; Jackson et al. 2005; Ullman 2006; Bentler 2006; Byrne 2006; Schreiber et al. 2006; Garson 2008; Byrne 2009).

In this chapter, for the development of the Safety Performance Index assessment tool, the adopted methodology from Yoo and Donthu (2001) and Avcılar (2010) was presented. Accordingly, calculations were performed based on the findings of the previous chapters, and formulation of the the Safety Performance Index of Construction Sites was explained in detail. Case studies were conducted at 11 international construction sites to assess their safety performance indices. Investigations were made and evaluation forms (including the full list of 168 observed variables in 16 latent dimensions of safety performance) were filled (taking into account of a scale between 0 to 100, where 0: Conformity is minimum, 100: Conformity is maximum, NA: If not applicable) at the construction sites by safety engineers of the companies working for the Case study projects. For all of the 11 Case studies; the Site Safety Performance Indices and the safety performance level of each 16 latent dimensions were calculated. For illustration purpose, detailed information regarding the calculation of the Site Safety Performance Index of Case study #1 was given and the items (factor loadings of the observed variables, relative weights of the observed variables, updated relative weights of the observed variables, site evaluations of the observed variables, the cumulative weighted mean of the site observations of each latent dimension, standardized path coefficients of the latent dimensions, relative weights of the latent dimensions, updated relative weights of the latent dimensions, Safety Performance Indices of construction sites) utilized in the formula were explained. Possible scenarios and their reflection to the developed formula were explained. Then, in each Case study, Safety performance levels of latent dimensions in descending order were shown in tables and figures. The Site Safety Performance Indices of 11 Case studies were benchmarked and results were demonstrated in descending order. Finally, a proposal of a short (simple) model (48 observed variables in 16 latent dimensions) as an alternative to the full model (168 observed variables in 16 latent dimensions) was explained. Results of safety performance by the short (simple) model and the full model were compared for Case studies #1 to #11. Deviations of the results of the short model from the results of the full model were calculated. The average deviation of the short model results from full model results was found to be + 3,14%, smaller than 5%, therefore it was found quite reasonable to utilize the proposed short model taking the advantages of its simplicity, fastness and reasonable accuracy.

CHAPTER 10

THE DEVELOPMENT OF SITE SAFETY PERFORMANCE (SSP) SOFTWARE AND APPLICATION FOR MOBILE DEVICES ON A CROSS-PLATFORM

In this chapter, the development of a Site Safety Performance (SSP) web application software and SSP mobile application for mobile devices on a cross-platform will be explained.

10.1 Introduction

Mobile applications for smartphones and other devices are having a widespread impact in many sectors of society. Mobile applications can be broadly classified into three categories namely native mobile, mobile-web and hybrid mobile applications (Nagesh and Caicedo 2012).

The native mobile applications, as the name suggests, are built specifically for a particular mobile devices and its operating system. Native mobile applications are able to work across multiple devices, separate versions of the application required (Karadimce and Bogatinoska 2014). A native application is downloaded from a web store and installed on the device (Lionbridge 2012).

A mobile-web application is normally downloaded from a central web server each time it is run, although applications built using HTML5 (Hypertext Markup Language) can also be run on the mobile device for offline use (Lionbridge 2012).

The hybrid mobile application, from the user interface, looks like browser based, with a native application wrapped around it providing access to device native functionality (Lionbridge 2012). Hybrid frameworks allow the use of web technologies for applications development with native access to device's resources (Singh 2013).

The basic information about various mobile application development platforms will be presented and the development of a cross-platform mobile application (Site Safety Performance (SSP)) for mobile devices will be presented in the following parts.

10.2 Native, mobile-web and hybrid mobile platforms

A native mobile application is a program that has been developed for use on a particular platform or device (Karadimce and Bogatinoska 2014). Native applications are developed using mobile software development kits (SDKs), tools and languages that are native to a particular mobile OS. For example, the development of Android applications is commonly done by using the Android SDK, Java and an integrated development environment (IDE) tool such as Eclipse. Iphone Operating System (iOS) applications are developed using the iOS SDK, X-code and Objective C. Blackberry applications can be developed using the Blackberry SDK, J2ME and Eclipse. The final deliverable in each case will be either an .apk (Android), .ipa (iOS) or .jar (Blackberry) file. Once developed, an application can be uploaded to an application store (Android Market, Apple Store or Blackberry application World) for widespread use (Nagesh and Caicedo 2012).

A mobile-web application is a web based application designed for smartphone and tablet use, and accessed through the mobile device's web browser (Karadimce and Bogatinoska 2014). These are suited for mobile websites like m.facebook.com, m.yahoo.com, m.cricinfo.com. These applications are developed using cross-platform SDKs and open source libraries such as jQuery (jQuery 2006). The user interface (UI) is developed in HTML5 (for structuring content), JavaScript (for interactive functionality) and CSS (for applying visual styles). The final deliverable is a set of files that can be hosted on a web server and the application can be accessed using an instance of a web browser (Nagesh and Caicedo 2012).

Hybrid mobile applications are a combination of the previous two application types. Hybrid applications are part native, part web applications (Karadimce and Bogatinoska 2014).These applications are developed using open source libraries but also have access to some of the native capabilities of a device such as camera, global positioning system (GPS), accelerometer, file system etc. The degree of access to device features is not comparable to that of native mobile applications but it is better than that of mobile web applications. The UI is developed by either HTML5 or JavaScript and the logic is defined by JavaScript. These tools usually convert a mobile-web app into a native application (Nagesh and Caicedo 2012). Table 10.1 and Figure 10.1 gives an overall comparison of mobile applications:

Table 10.1: Overall comparison between the three types of mobile applications (Source: Nagesh and Caicedo 2012)

Type of Application/ Features	**Native mobile Apps**	**Mobile-Web Apps**	**Hybrid Apps**
Programming Language	Java(Android), Objective C(iOS), J2ME(BB)	HTML5 and JavaScript	HTML5 and JavaScript
Executable	Binary (.apk,. ip,. jar)	HTML + JavaScript	Binary
Distribution	Appstore, Market	Hosted on a web server, hyperlink	Either appstore or hyperlink
Execution of Apps	Directly by Operating System	By Web browser	By operating system, web portions executed by browser
API Usage/Access	Full Access to operating system API's	No Access to OS API's	Limited access to OS API's
Device Access	Full Access	Limited Access	Full Access
Speed of Apps	Very fast	Medium	Very fast
Development Cost	Expensive	Reasonable	Reasonable
Approval Process	Mandatory	None	Low overhead
SDK's, Tools	Android, iOS, BB, Symbian, Windows SDK's	jQuery, jQtouch, Sencha	Titanium, PhoneGap, Rho Mobile

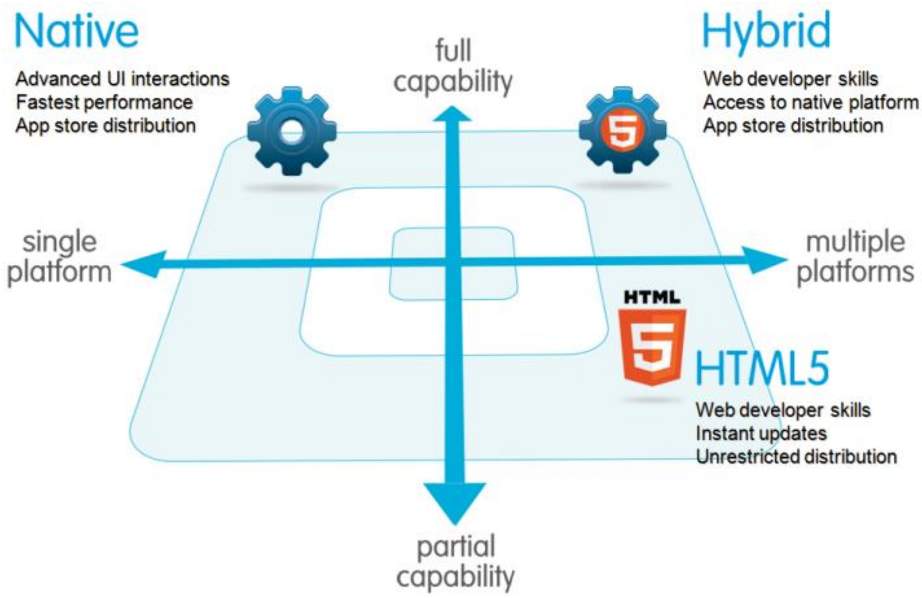


Figure 10.1: Native, web-based and hybrid mobile applications (Source: Jern 2013)

10.3 HTML5

HTML5 is a structured language used to deliver content in World Wide Web (WWW). HTML5 is the newest version of the HTML standard which is now widely used to handle most of the content in the World Wide Web. It is not only supported by the normal desktop browsers such as Chrome, Firefox, Internet Explorer, Safari, but also the browsers included in many mobile platforms. HTML5 supports a new set of Application Programming Interfaces (APIs); and features to handle audio, video and UI design. It also adds some scripting APIs such as canvas elements, timed media playback, offline storage database, drag and drop, cross-document messaging, browser history management (Nagesh and Caicedo 2012).

The leading mobile platforms iOS, Android, Windows, Palm OS, and RIM (Research in Motion) provide HTML5 capable browsers. Hence HTML5 plays a major role in helping developers write mobile applications to multiple devices at once. The cross-platform nature of HTML5 and the fact that it is supported on most of the smart phone browsers make it easy for web developers to use their existing HTML and JavaScript knowledge in developing mobile-web applications (Nagesh and Caicedo 2012).

10.4 CSS3 (cascading style sheet)

Cascading style sheet is a language used to format the look and feel of a document written in a markup language. The markup language can be HTML, XML, XHTML and SVG. With CSS, the actual content of web pages is separated from definition of how it should be presented. The fonts, font size, color schemes, layouts are included in a CSS command file (stylesheet) and applied to the web pages. This improves the flexibility and the ease with which the web pages are developed. A CSS file is very simple and consists of many English keywords to specify the graphical definitions of the presentation styles for the elements in an HTML generated web page. CSS styles can be applied to all or part of a web page. An example of a simple CSS would be as follows (Nagesh and Caicedo 2012).

```
h1 { color: white; background-color: orange}
```

The above line of code applies a particular style to the text with heading h1. The color of the text is white and background color of the highlighted text is orange.

A CSS style file (style.css) can be made to affect the presentation of a web-page by incorporating the following call in the HTML file of the web-page:

```
<link rel=”stylesheet” href=http://www.xyz.com/css/style.css type=”text/css” />
```

The above line of code in the HTML page links the CSS file to the HTML page. The style sheet can be either a local CSS file or a file stored in an external server. Other ways of applying CSS is to embed the style definitions inside the HTML code of a web page.

CSS3 is the latest version of CSS where style definitions are defined in the form of blocks. The segmentation of rules in blocks helps the browser define and approve the rules more quickly than doing it in one single block. This improves the performance of web page rendering (Nagesh and Caicedo 2012).

10.5 JavaScript

JavaScript is an interpreted programming language with object-oriented (OO) capabilities. Syntactically, the core JavaScript language resembles C, C++, and Java, with programming constructs such as the if statement, the while loop, and the && operator. JavaScript is a dynamic programming language. It is most commonly used in web browsers, and, in that context, the general-purpose core is extended with objects that allow scripts to interact with the user, control the web browser, and alter the document content that appears within the web browser window. This embedded version of JavaScript runs scripts embedded within HTML web pages. It is commonly called client-side JavaScript to emphasize that scripts are run by the client computer rather than the web server (Flanagan 2006).

It is also used in server-side network programming with runtime environments such as Node.js (which is an open source, cross-platform runtime environment for server-side and networking applications), game development and the creation of desktop and mobile applications.

10.6 Cross-platform software development kits (SDKs)

Cross-platform mobile development has become more popular approach to deliver applications to various mobile platforms (Khandozhenko 2014). There are many SDKs and frameworks available to developers for the development of mobile applications that can work on several mobile operating systems. Apart from native SDKs for mobile operating systems such as Android, iOS, Blackberry and Windows Mobile, there are some interesting and innovative cross-platform SDKs with which developers can target multiple platforms and devices at a time. Using these SDKs, one can develop mobile-web, hybrid and native applications. This reduces a lot of the effort, time and resources required to develop applications for multiple platforms (Nagesh and Caicedo 2012).

Some of the most widely used cross-platform SDKs and HTML5 frameworks used to develop such applications are as follows: a) Rho Mobile, b) Appcelerator’s Titanium, c) Airplay SDK, d) Adobe Air, e) PhoneGap.

10.6.1 Rho Mobile

RhoMobile was founded in 2008 in Silicon Valley and was acquired by Motorola Solutions in late 2011 (Rho Mobile 2008). It produces an open source cross-platform SDK under an MIT license. Rho Mobile is based on Rhodes framework and is used to build native mobile applications. When developing an application with this tool, the UI of the application is written in HTML5 and the application’s controllers (logic) are written in Ruby. The platforms supported are Blackberry, Windows Mobile, Android, iPhone and iPad. Embedded RuBy (ERB) templates, HTML5, CSS and JavaScript are the programming languages used in this SDK (Nagesh and Caicedo 2012).

10.6.2 Appcelerator Titanium

Titanium was released in December 2008 by Appcelerator Inc. (Appcelerator Titanium 2008). It is a cross-platform SDK that can deliver native applications for iOS and Android and has beta support for Blackberry. JavaScript is the main language used to write mobile applications with the support of HTML5 and CSS. It is an open source SDK which converts the JavaScript code to native code (Objective C or Java) during runtime. Applications written with Titanium have same look and feel as if the applications are written natively. The entire SDK is open source, but there are some licensed modules which can be bought. The Integrated Development Environment (IDE) used to write Titanium applications is Titanium Studio which is shipped with the SDK. The IDE has an inbuilt JavaScript compiler which checks for dependencies, analyzes and optimizes code. Then the platform compiler compiles the JS code to native code (Objective C for iOS and Java for Android). The SDK's APIs are pure JavaScript and are mapped to native API's during run time. Major APIs include support for UI, Network, Map, Geo Location, Gestures, Accelerometer, Database, File System, Media etc. Titanium also supports JSS files where JSON-style properties can be added for an object or an application (Nagesh and Caicedo 2012).

10.6.3 AirPlay SDK

AirPlay SDK was founded in 1998 (AirPlay 1998). The Airplay SDK (Marmalade) is a licensed SDK which offers solutions for cross platform and native (C/C++) mobile and desktop applications. It supports many devices with OSs such as iOS, Android, Symbian, Windows, WebOS and Bada (Samsung). The programming language used is C/C++ and has access to all standard libraries and language features. The executable is a single binary file with native Central Processor Unit (CPU) instructions that runs identically across all platforms. The IDEs supported are Microsoft Visual C++ and Xcode with support of X86 compilers both on Windows and Mac. It is mostly used for cross-platform game application development since the SDK has rich support for Open GL ES 2.0 which is suitable for rich 2D and 3D applications (Nagesh and Caicedo 2012).

10.6.4 Adobe AIR

Adobe AIR (Adobe Integrated Runtime) was released in 2009 by Adobe Systems for building rich internet based mobile and desktop applications (Adobe Air 2009). It is a cross-platform run time environment and SDK available for developing applications for iOS, Android and Blackberry devices. HMTL5, JavaScript, Adobe Action Script, and MXML (Flex) are the languages supported. The Adobe tools required for development are available for free and can be integrated to an open source IDE like Eclipse or to Adobe's Flex Builder 3. Flex Builder is available as plug-in to Eclipse and also as a standalone toolkit. Adobe Air internally uses a flash player as the run time environment and flash applications must specifically be built for the Adobe Air runtime in order to utilize the additional features provided such as file system integration, native client extensions, native window screen/task bar integration, Accelerometer. It also has built in support for SQLlite (software library), database access via web services and encrypted local storage (Nagesh and Caicedo 2012).

10.6.5 PhoneGap

PhoneGap was first released in 2005 by Nitobi Inc. (PhoneGap 2005). PhoneGap is an open source cross-platform mobile application development framework which through the use of HTML5, CSS and JavaScript allows for the development of applications for iOS, Android, Blackberry, Symbian, Windows, WebOS, Bada and Palm devices as demonstrated in Figure 10.2. The final product of a PhoneGap application is a binary application archive that can be distributed through standard application ecosystems. For iOS applications the output is an IPA file (iOS Application Archive file), for Android applications the output is an APK file (Android Package File), for Window Phone the output is a

XAP file (Application Package File), etc. These are the same application packaging formats used by "native" applications, and can be distributed through the appropriate ecosystems (iTunes Store, Android Market, Amazon Market, BlackBerry App World, Windows Phone Marketplace, etc.).

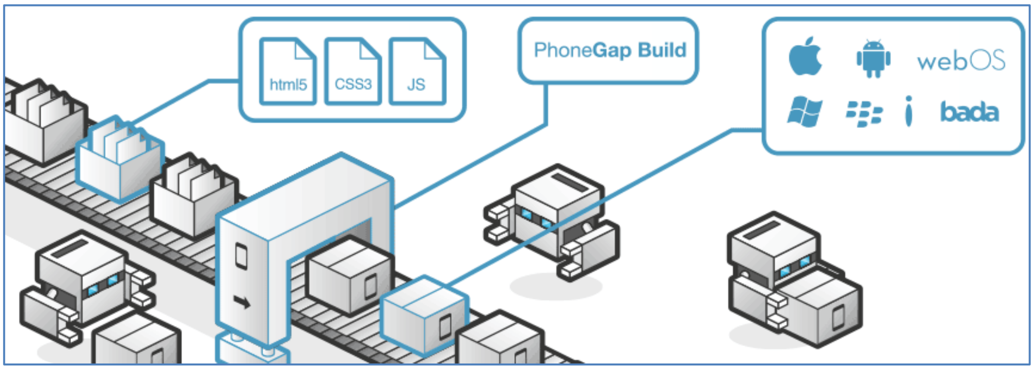


Figure 10.2: Demonstration of PhoneGap process framework (Source: PhoneGap 2005)

It is based on open web-standards which means that the application can be run and tested on common web browsers such as Chrome and Safari. The application creation process is very similar to that of web pages creation, except for the installation and deployment stages.

The user interface in a PhoneGap application is rendered with HTML5 and the logic is built with JavaScript. PhoneGap also provides facility to use local storage such as cookies for session maintenance, Web SQL database access, HTML5 local storage and indexed storage.

Additionally, PhoneGap provides access to the following device functionalities: Accelerometer – Device Motion Sensor, Geolocation- GPS Sensor, Compass, Camera, Capture – audio, video and image capture capabilities, Media- Allows record and playback of Audio, Contacts Database, File System, Connection Type, Device Information. Some of the core events that are supported by PhoneGap are:

DeviceReady, pause and resume, online and offline, menu button, search button, start call button and end call button, volumedownbutton and volumeupbutton.

PhoneGap applications can also communicate with the remote web servers. The servers can be public (twitter, facebook) or any Customer Relationship Management (CRM) based back end application (Nagesh and Caicedo 2012). According to VisionMobile (2013), the breakdown of the top Cross Platform Tools (CPT) was shown in Table 10.2:

Table 10.2: The breakdown of the top Cross Platform Tools (Source: VisionMobile 2013)

No:	Cross Platform Tools	% of Developers using the platform
1	PhoneGap	34%
2	Appcelerator	21%
3	Adobe Air	19%
4	Sencha	12%
5	Qt	11%
6	Unity	9%
7	Corona	7%
8	Mono	7%
9	Marmalade	6%

As shown in Table 10.2, PhoneGap tops CPT rankings, used by 34% of developers, followed by Appcelerator and Adobe Air with 21% and 19% developer mindshare respectively.

Hybrid applications combine the best of both the native and web worlds. They create a “bridge” between the browser and the device APIs, so the hybrid mobile application takes full advantage of all the features that smartphones and tablets have to offer (Karadimce and Bogatinoska 2014).

Considering PhoneGap's advantages of being a standards-based, open source development framework, free to download, with community-built development tools and plugins (Karadimce and Bogatinoska 2014) and being the most popularly growing platform (VisionMobile 2013), in this study, PhoneGap is selected to develop a hybrid mobile application.

10.7 Development of the site safety performance (SSP) web application software

In this study, a Site Safety Performance (SSP) web application software was developed by using the HTML5, CSS3 and JavaScript coding languages. The introduction, model selection, full model, short model, results and exit pages of the developed Site Safety Performance (SSP) web application software will be explained in this part.

10.7.1 Introduction page

The explorer view of the developed index.html file for Site Safety Performance (SSP) web application software was demonstrated in Figure 10.3 below. When the SSP web application software is started by triggering the index.html file, an introductory page is displayed on the screen with the explanations below:

"Site Safety Performance (SSP) application has been developed within the scope of an ongoing Ph.D. thesis study "A Fuzzy Structural Equation Model to Analyze Relationships Between Determinants of Safety Performance in Construction Sites: Development of a Safety Performance Index Assessment Tool" in the Department of Civil Engineering at Middle East Technical University.

SSP application is intended to measure the "Safety Performance Index of Construction Sites" and aimed to improve the construction safety."

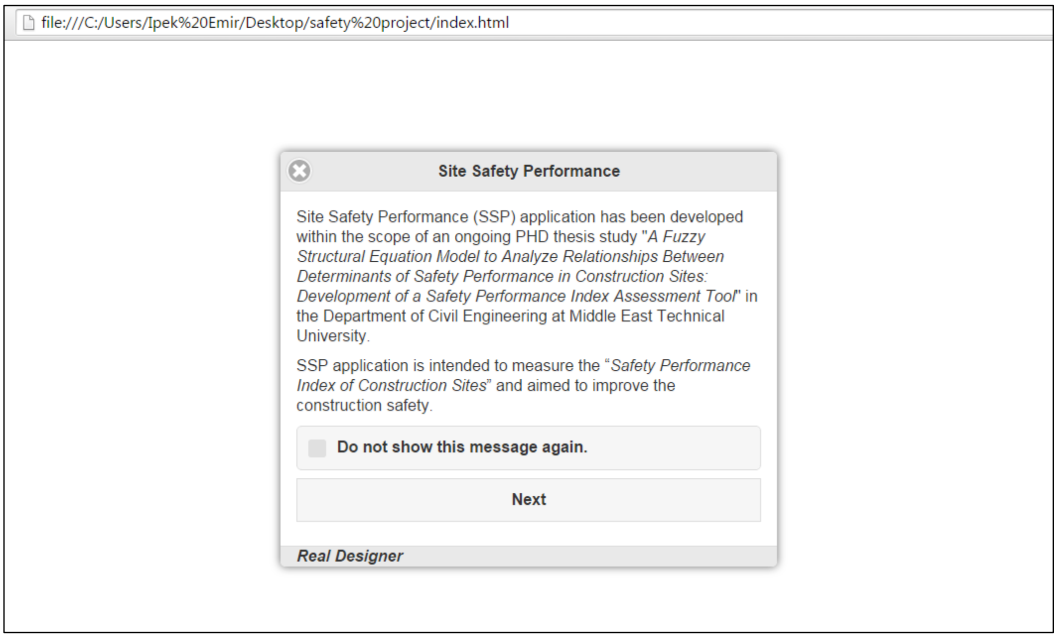


Figure 10.3: The explorer view of the developed index.html file for Site Safety Performance (SSP) web application

10.7.2 Model selection page

When the next button is triggered, the model selection page is displayed on the screen. In the model selection page of SSP web application software, following explanations are given to describe the models to be selected as seen in Figure 10.4:

"SSP includes two models namely full model and short model for the calculation of "Safety Performance Index of Construction Sites".

Full model includes a whole list of 168 observable variables in 16 latent dimensions affecting Safety Performance.

Short model includes a short list of 48 observable variables in 16 latent dimensions affecting Safety Performance.

Please, click the model that you prefer to start. Short model predicts the Safety Performance with an acceptable accuracy and requires less time to complete."

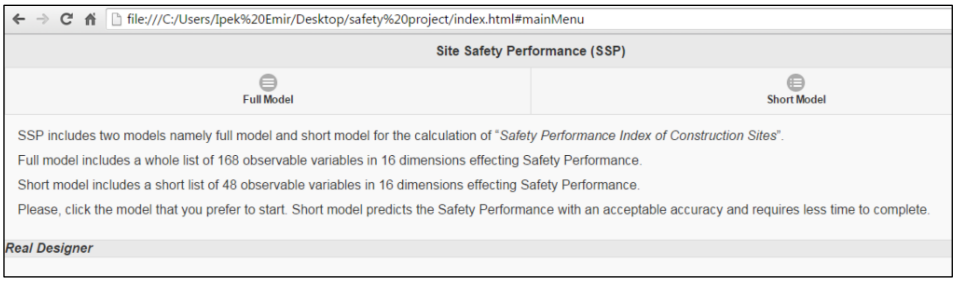


Figure 10.4: The model selection page of Site Safety Performance (SSP) web application

10.7.3 Full model page

When the full model button is triggered, the full model page is displayed on the screen. In the full model page of SSP web application software, following explanations are made as seen in Figure 10.5:

"Full model includes a whole list of 168 observable variables in 16 latent dimensions affecting Safety Performance.

Please evaluate the observable variables by using slider bars within a scale of 0-100 according to their conformity level at the construction site.

Evaluation of variables
(scale: 0-100)
0: Conformity is minimum.
100: Conformity is maximum.

NA: *If not applicable.*

After the evaluation, please click the results button to see the full model results of Safety Performance of the construction site."

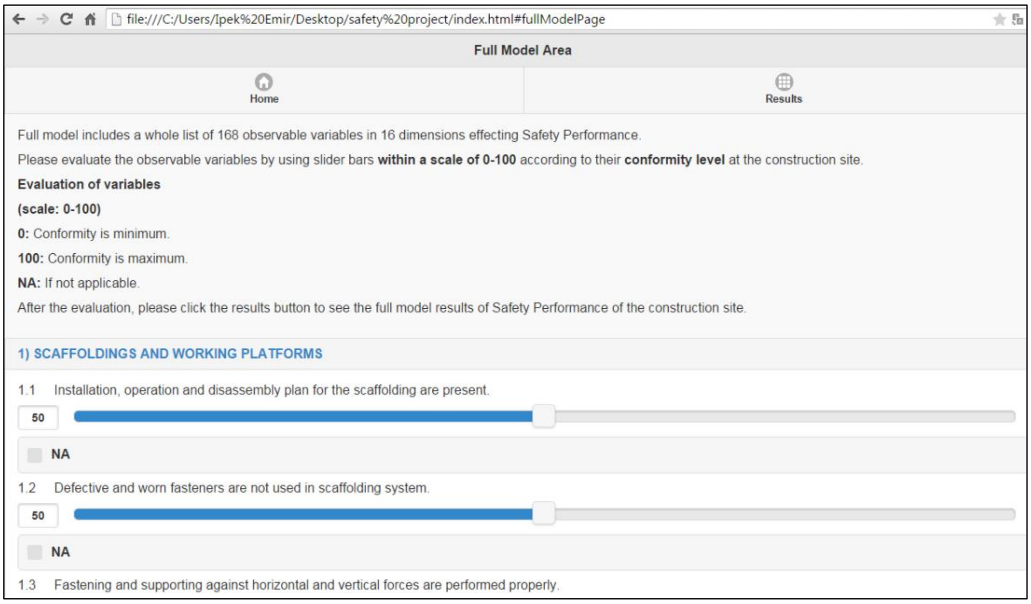


Figure 10.5: The full model page of Site Safety Performance (SSP) web application

10.7.4 Short model page

When the short model button is triggered, the short model page is displayed on the screen. In the short model page of SSP web application software, following explanations are made as seen in Figure 10.6:

"Short model includes a short list of 48 observable variables in 16 latent dimensions affecting Safety Performance.

Please evaluate the observable variables by using slider bars within a scale of 0-100 according to their conformity level at the construction site.

Evaluation of variables

(scale: 0-100)

0: Conformity is minimum.

100: Conformity is maximum.

NA: If not applicable.

After the evaluation, please click the results button to see the short model results of Safety Performance of the construction site."

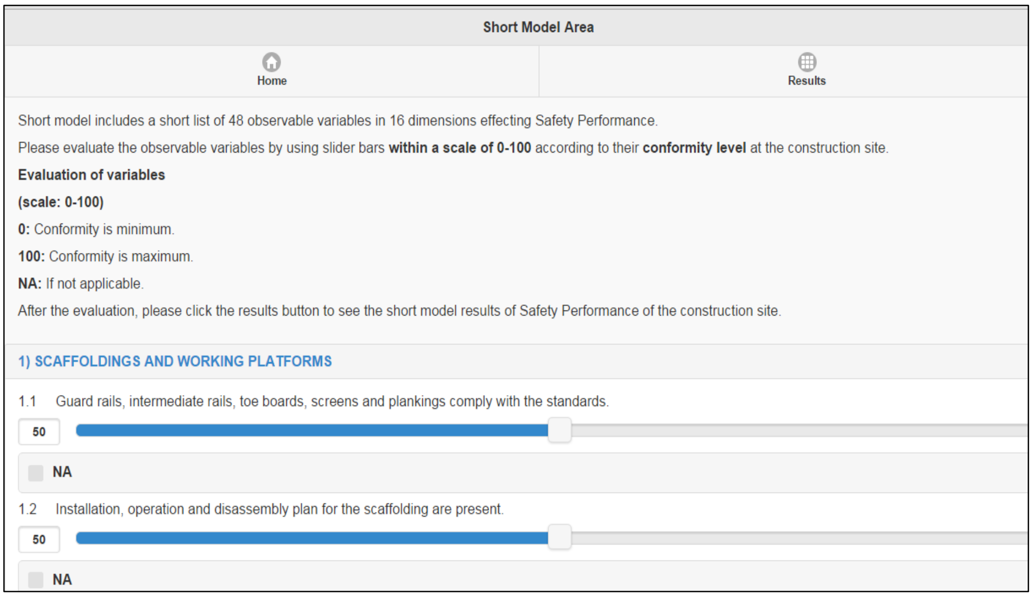


Figure 10.6: The short model page of Site Safety Performance (SSP) web application

10.7.5 Results pages

Results page of full model:

When the results button is triggered in full model menu, the results page is displayed on the screen. In the results page of SSP web application software, following explanations are made and results are demonstrated as seen in Figure 10.7:

"This page demonstrates:

- *the entry values,*
- *calculated levels of each latent dimension affecting Safety Performance, and*
- *the result of Safety Performance Index of the construction site."*

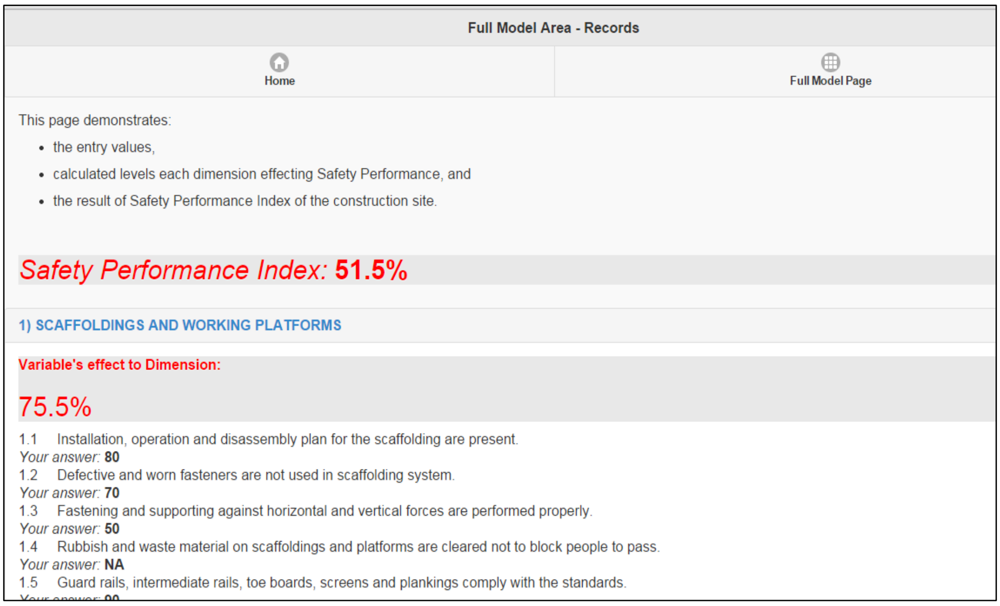


Figure 10.7: The results page of full model of Site Safety Performance (SSP) web application

Results page of short model:

When the results button is triggered in short model menu, the results page is displayed on the screen. In the results page of SSP web application software, following explanations are made and results are demonstrated as seen in Figure 10.8:

"This page demonstrates:

- *the entry values,*

- *calculated levels of each latent dimension affecting Safety Performance, and*
- *the result of Safety Performance Index of the construction site."*

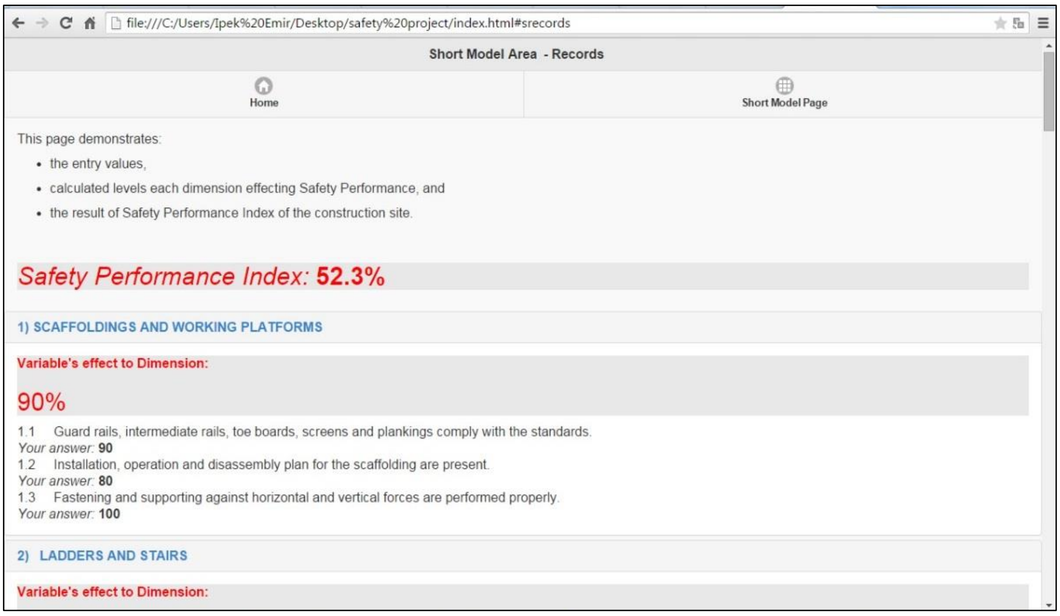


Figure 10.8: The results page of short model of Site Safety Performance (SSP) web application

10.7.6 Exit page

When "X" button on the explorer window is clicked, program saves the data and closes down. If SSP web application software is re-started, users can continue to make evaluation of the observable variables. SSP web application software never expires. Data and results are always available, when a change is made in the evaluation of any observable variable, the results are calculated and changed accordingly and can be reached from results page simultaneously.

10.8 Development of Site Safety Performance (SSP) application for mobile devices on a cross-platform (by PhoneGap)

In this study, a Site Safety Performance (SSP) mobile application was developed by using PhoneGap built on the previously developed SSP web application software. The introduction, model selection, full model, short model, results and exit pages of the developed Site Safety Performance (SSP) application for mobile devices will be explained in this part.

10.8.1 Introduction

Applications developed by PhoneGap can be distributed to various vendor application stores (example: Apple Store) and installed on an end-user's device like any other native application. PhoneGap provides an intuitive and friendly way to develop mobile applications. PhoneGap Build is a cloud service for compiling PhoneGap applications. Some of the benefits PhoneGap Build provides are; PhoneGap Build does not involve installing and maintaining multiple native SDKs as well as the Cordova/PhoneGap SDK, it maximizes the developer's productivity while minimizing production time, team members can be added to work collaboratively and roles can be developed within PhoneGap Project (PhoneGap 2005).

10.8.2 Environment setup for PhoneGap

In this part, how the basic environment is set up in order to make mobile applications will be presented. PhoneGap supports offline creation of applications using cordova command line interface and Github repository. As mentioned in the previous parts, PhoneGap provides a way for developers to develop mobile applications using technologies of HTML, CSS, and JavaScript. PhoneGap allows its users to upload the data contents on website and it automatically converts it to various application files.

From developers’ perspective, an application should have the following items included in its package: Configuration files, icons for application, and information or content (built using web-technologies). A web application needs only one configuration file that should be adequate to configure all its necessary settings. Its name is “config.xml”. This file contains all the necessary information required to compile the application. There are devices of various sizes having same mobile operating system, so to target an audience of one platform, it is needed to furnish icons of all the mobiles types too. It is important that icons should be prepared of exact shapes and sizes as required by particular mobile operating system. As the content, offline websites are copied to local hard-drive and accessed whenever the user needs without any internet connection. Likewise, offline web applications let developer create a web application that is downloaded to the mobile devices of a user who can access that offline. Figure 10.9 represents a sample folder structure for an offline application. At root directory, it requires only two files, “config.xml” and “index.xml” (Tutorialspoint 2006).

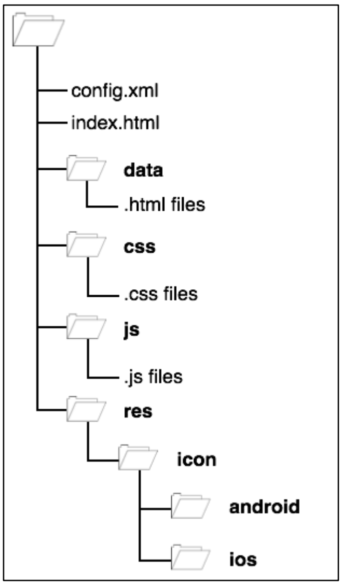


Figure 10.9: Representation of a sample folder structure for an offline application (Source: Tutorialspoint 2006)

The “config.xml” contains application configuration settings and the “index.html” file contains homepage of web-contents. All links inside all html files should contain relative path only. Absolute path or base href tag should not be used.

10.8.3 Application compilation by PhoneGap

After preparing the Site Safety Performance (SSP) web content files, they were organized in the folder structure as mentioned in previous parts. These files need to be zipped with a standard zip tool that will be used in the next parts. In this part, the process of transforming the Site Safety Performance (SSP) web contents to a mobile device application format which can be uploaded to online application stores will be mentioned.

PhoneGap accepts user login created on GitHub or using AdobeID. GitHub is a repository service where users can upload their contents and use them by providing their Uniform resource locator (URL) references. For example, the developed web content can be uploaded to GitHub and then called directly to PhoneGap (Tutorialspoint 2006). An Adobe ID should be created by registering from the web link: https://build.phonegap.com/. A new window opens as displayed in Figure 10.10 below:

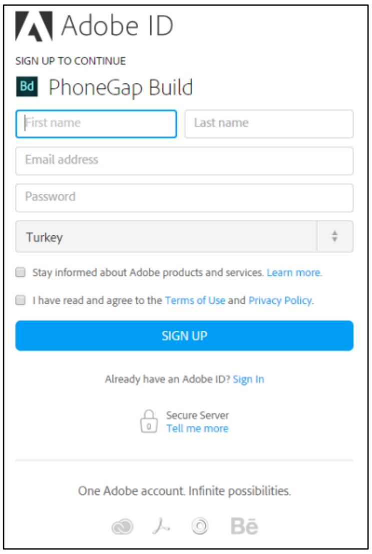


Figure 10.10: Registration page of PhoneGap Build

After filling in the details and clicking on sign up, one can now login with the same user-id to PhoneGap. By default, this page leads to PhoneGap console as displayed in Figure 10.11 below:

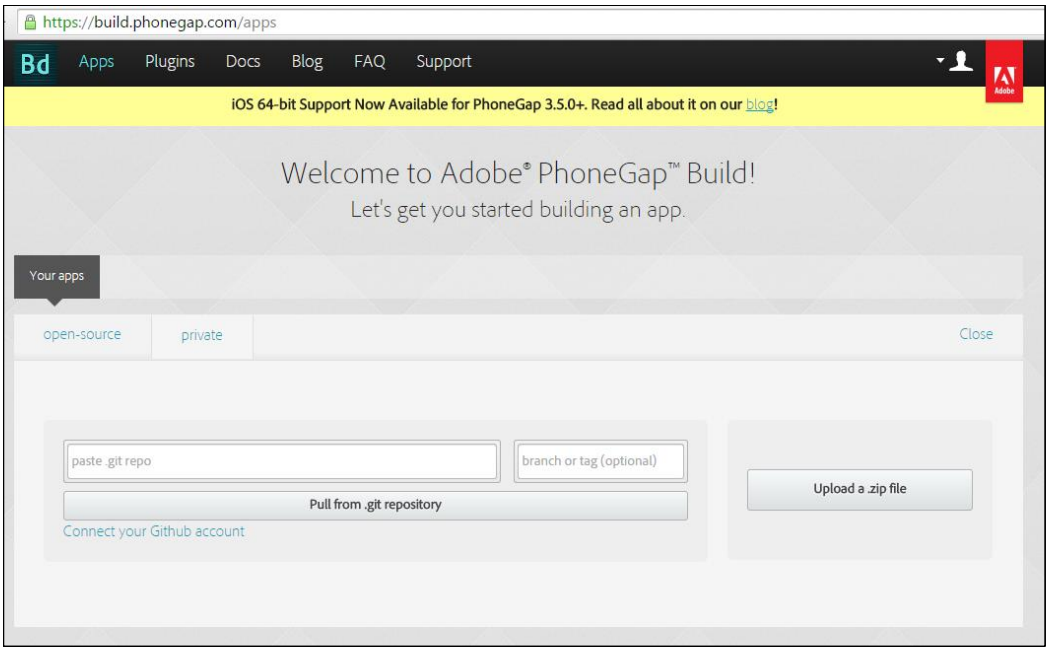


Figure 10.11: Console of the PhoneGap Build

After clicking ‘Upload a .zip file’ and uploading the .zip file including all web-contents and configurations for Site Safety Performance (SSP) application, the following window was displayed on the screen as shown in Figure 10.12 and the barcode page for SSP Mobile application by PhoneGap Build was generated in Figure 10.13.

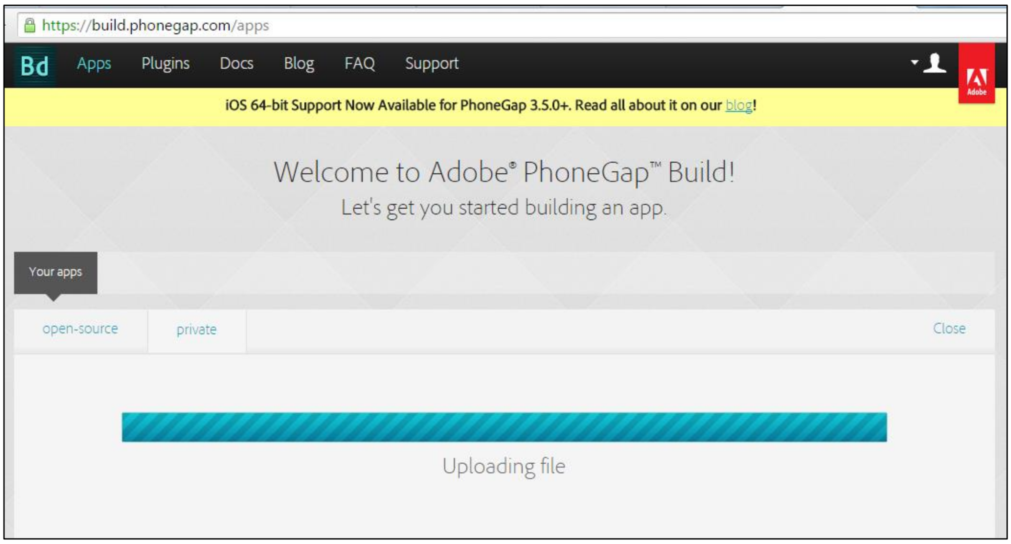


Figure 10.12: Upload page of the PhoneGap Build

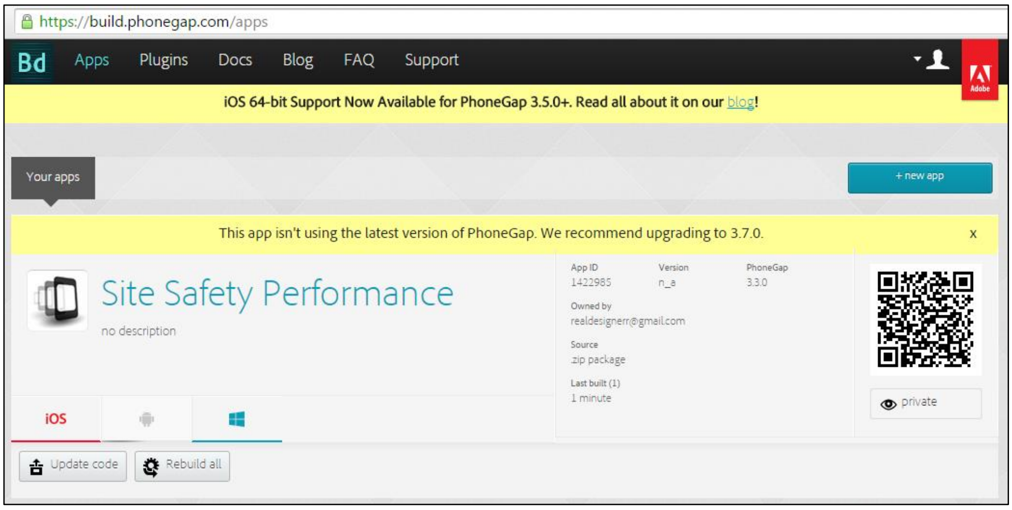


Figure 10.13: Barcode page of the developed SSP mobile application by PhoneGap Build

10.8.4 Signing and uploading the SSP application to google play store

It is essential for any application to be signed by its developers or developing organization to keep things in order. A keytool should be generated by executing the "*keytool -genkey -v -keystore my_keystore.keystore -alias TutorialsPoint -keyalg RSA -keysize 2048 -validity 10000*" command. This generates "my_keystore.keystore" file, which is needed for the application to be signed and uploaded to google play store (Tutorialspoint 2006).

As can be seen in Figure 10.14 that, iOS application development process failed, since any signed key was not provided. This study is only concentrated on creating an android application and as can be seen in Figure 10.14 that the SSP android application was developed by PhoneGap Build.

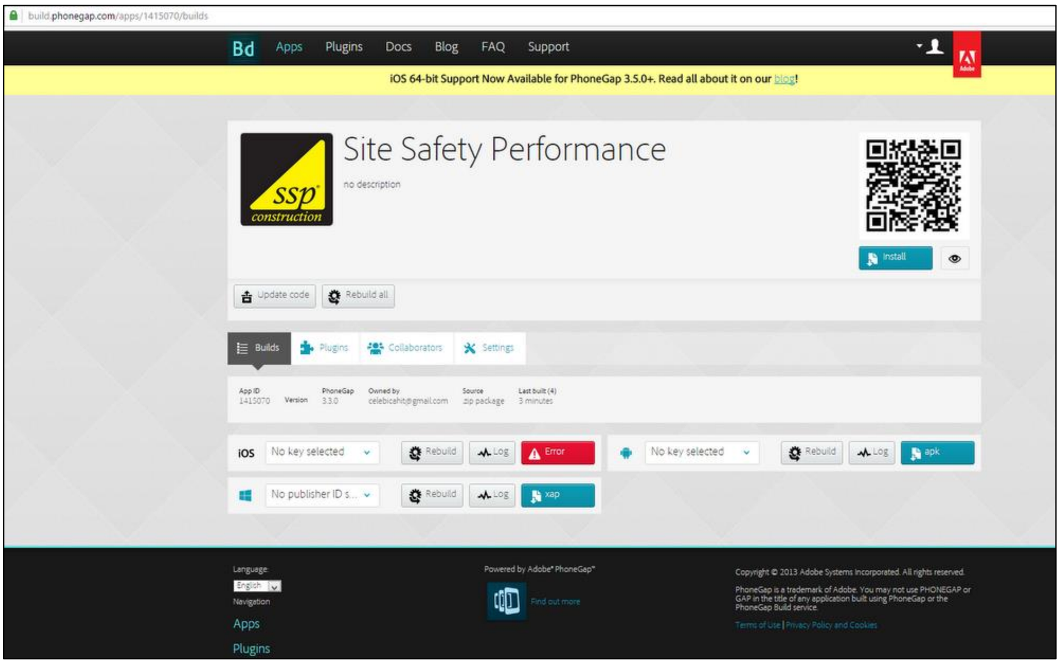


Figure 10.14: Platform view of the developed SSP mobile application by PhoneGap Build

To upload the developed SSP android application to google play store, the “No key selected” icon in Figure 10.15 should be clicked and “add a key” needs to be triggered.

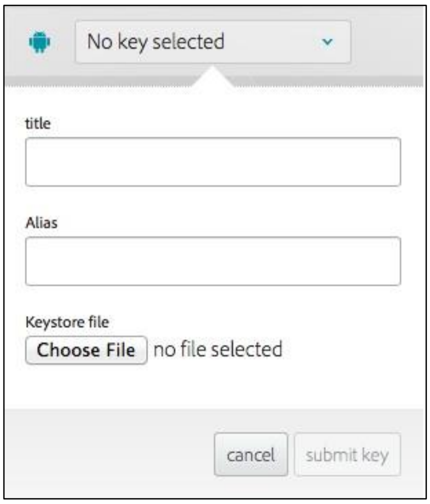


Figure 10.15: Adding a keystore file

After providing title and alias, submitting the previously generated keystore file as in Figure 10.14, clicking the “rebuild” button, the uploading process of SSP mobile application to google play store is finished.

10.8.5 Installation of the site safety performance (SSP) mobile application

The download web address and barcode of SSP application for mobile devices can be seen in Figure 10.16 below. SSP application can be automatically downloaded from this web address, barcode or google play store.

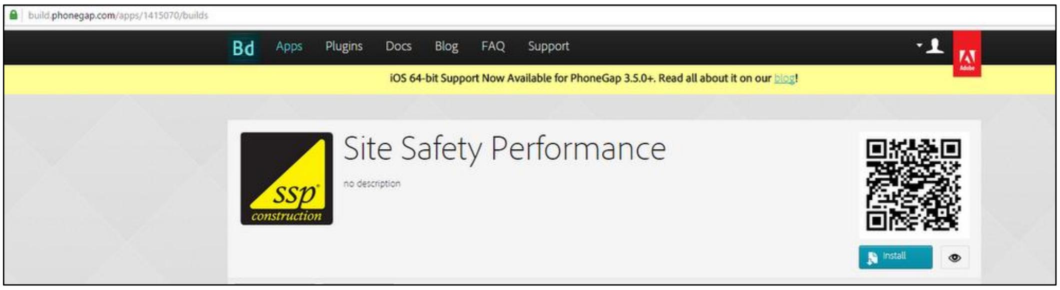


Figure 10.16: The web and barcode page of the SSP mobile application

In order to download the SSP application, open link button should be triggered as shown in the Figure 10.17.

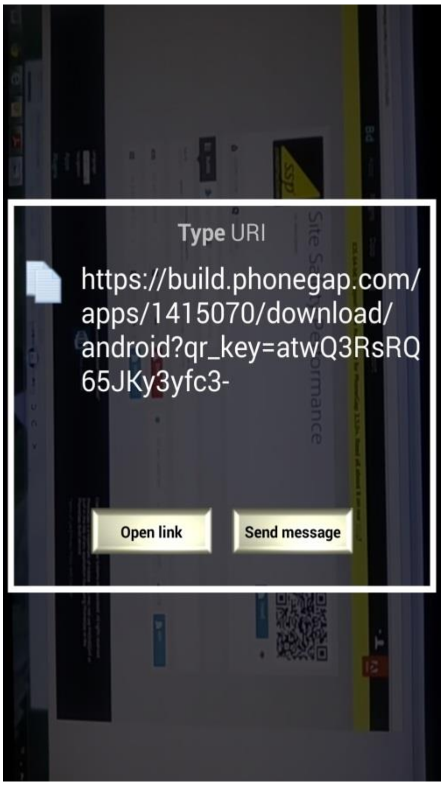


Figure 10.17: Download URL link for SSP mobile application for mobile devices

The mobile phone view of the downloaded SSP application to the mobile device was shown in Figure 10.18.

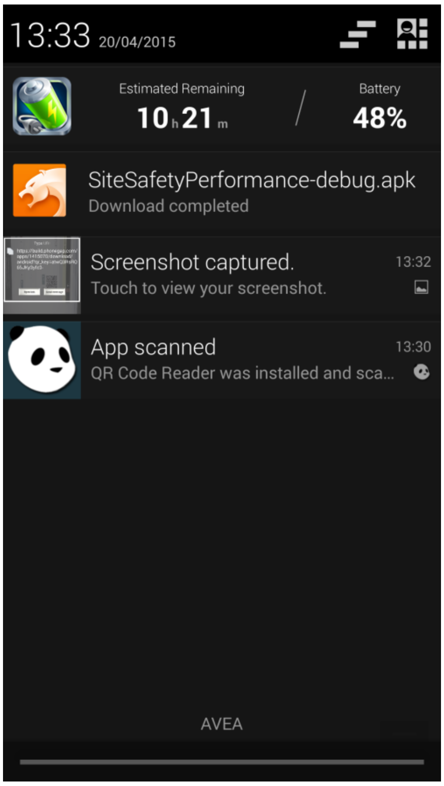


Figure 10.18: The mobile phone view of the downloaded SSP mobile application

In Figure 10.19, and 10.20 the items that SSP program requires to access in order to install was demonstrated.

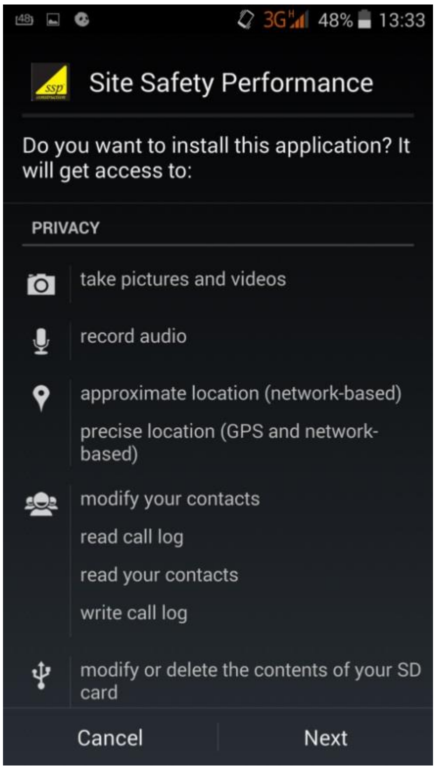


Figure 10.19: Installation page of SSP mobile application-1

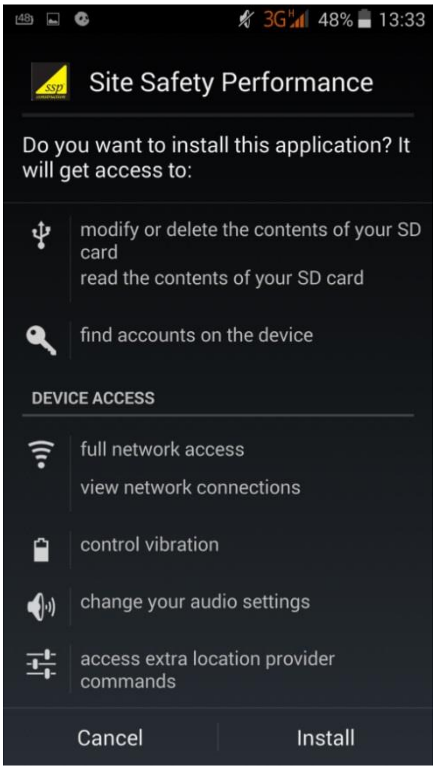


Figure 10.20: Installation page of SSP mobile application-2

When the next button in Figure 10.19 and install button in Figure 10.20 was triggered, device started to install the SSP application as shown in Figure 10.21, and the installation was finished as seen in Figure 10.22.

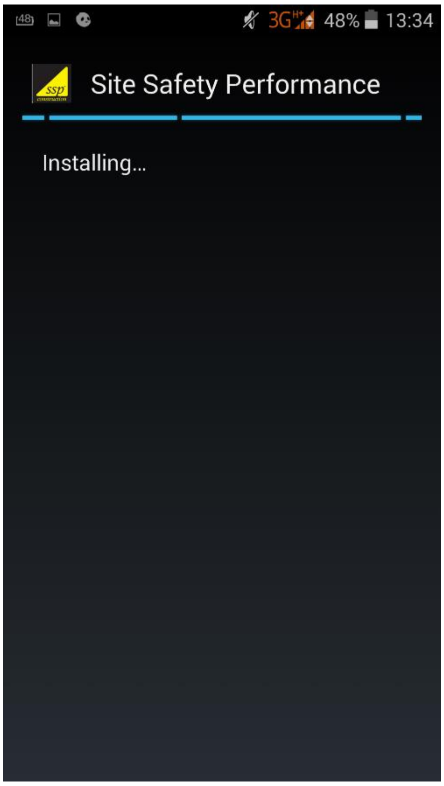


Figure 10.21: Installation of SSP mobile application-1

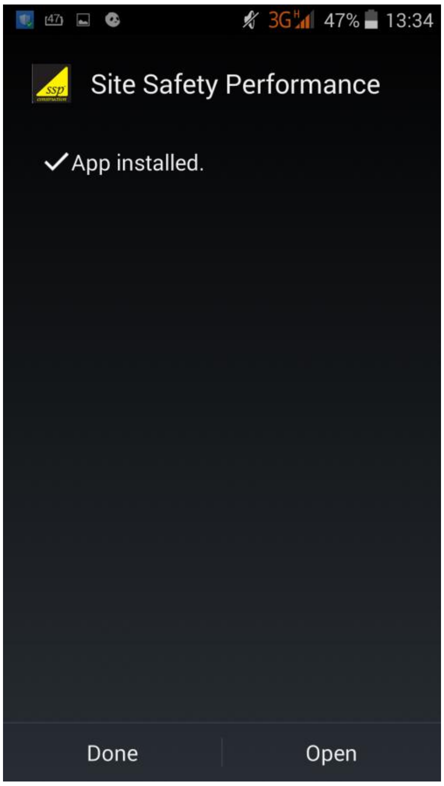


Figure 10.22: Installation of SSP mobile application-2

After the installation of SSP application on the mobile device, a shortcut was created in the applications page as shown in Figure 10.23.

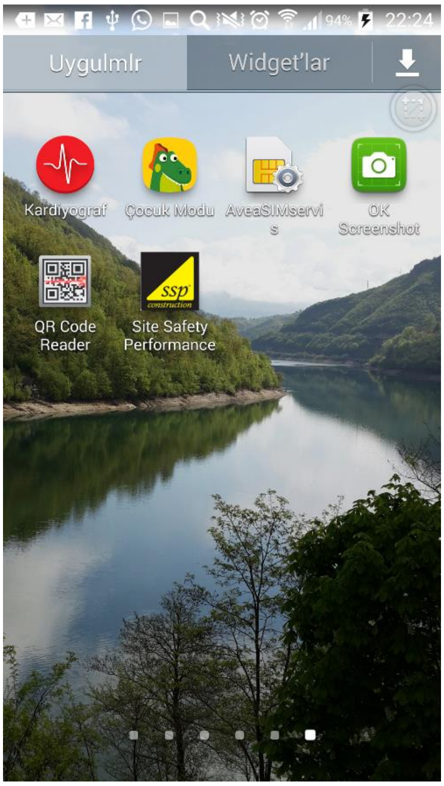


Figure 10.23: Mobile application shortcut created in the applications page

10.8.6 Introduction page

When the Site Safety Performance (SSP) mobile application is started by triggering the program's shortcut as shown in Figure 10.23, an introductory page is displayed on the screen of the mobile phone as shown in Figure 10.24 with the explanations below:

"Site Safety Performance (SSP) application has been developed within the scope of an ongoing Ph.D. thesis study "A Fuzzy Structural Equation Model to Analyze Relationships Between Determinants of Safety Performance in Construction Sites: Development of a Safety Performance Index Assessment Tool" in the Department of Civil Engineering at Middle East Technical University.

SSP application is intended to measure the "Safety Performance Index of Construction Sites" and aimed to improve the construction safety."

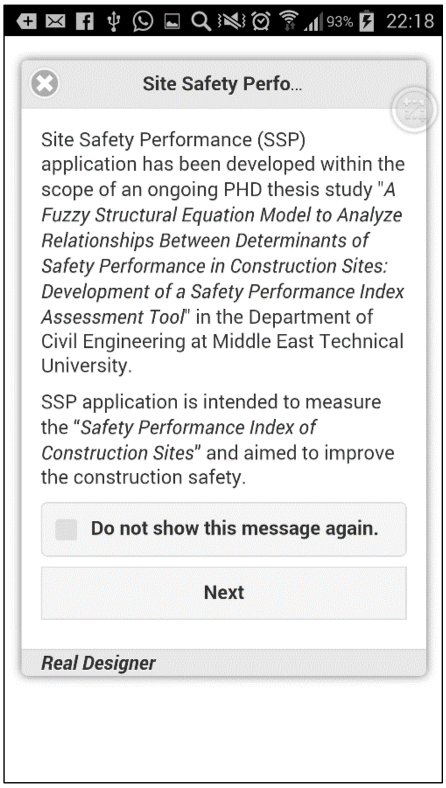


Figure 10.24: The introduction page of Site Safety Performance (SSP) mobile application

If the mobile device is tilted 90 degrees in clockwise or counter-clockwise direction, SSP application adapts itself and shows the tilted view as can be seen in Figure 10.25 and 10.26.

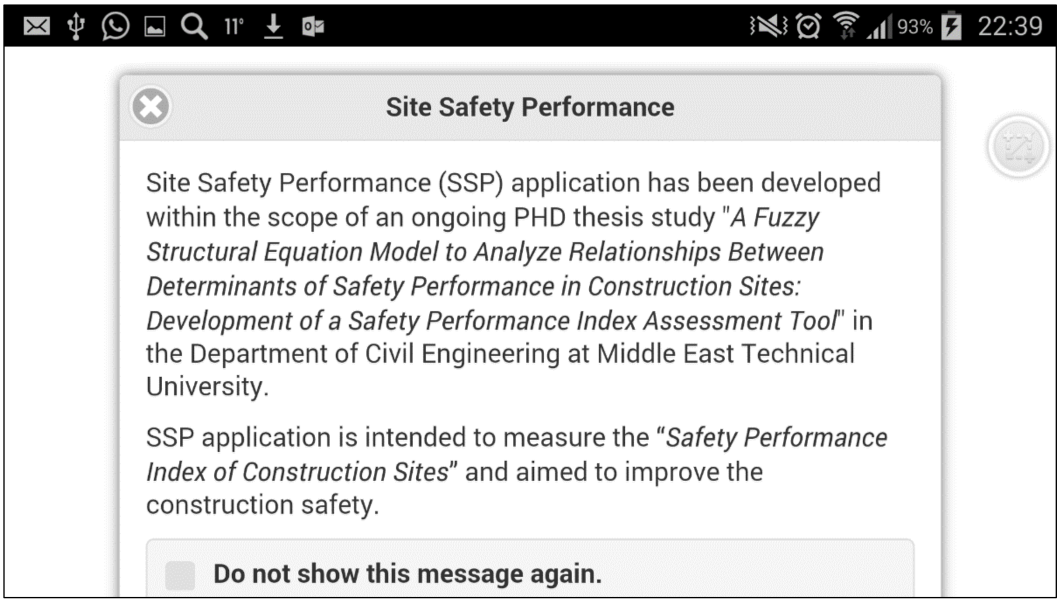


Figure 10.25: The tilted view introduction page of Site Safety Performance (SSP) mobile application-1

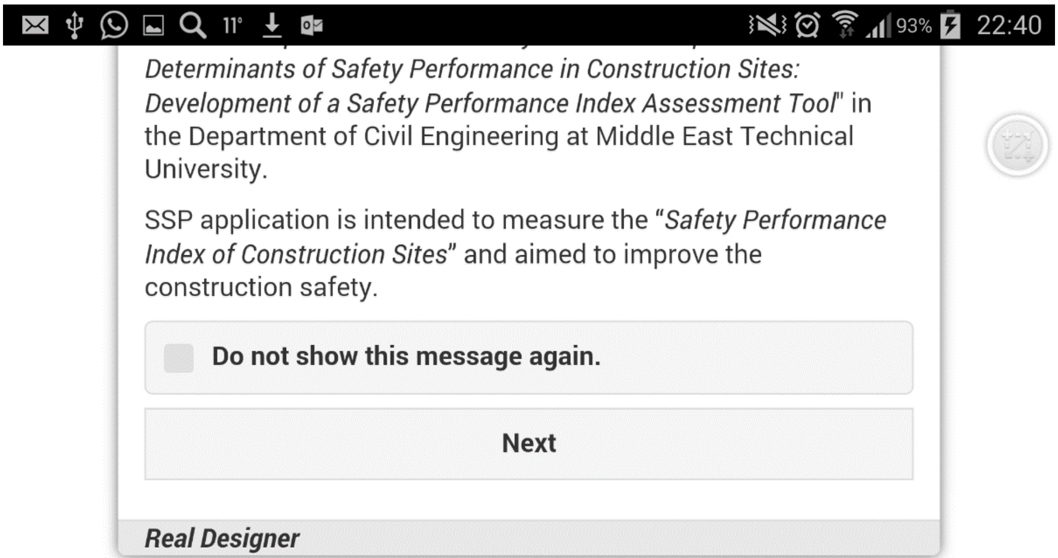


Figure 10.26: The tilted view introduction page of Site Safety Performance (SSP) mobile application-2

After triggering the next button in Figure 10.24 or Figure 10.26, SSP model selection page opens as shown in Figure 10.27.

10.8.7 Model selection page

In the model selection page of SSP application, following explanations are given to describe the models to be selected as seen in Figure 10.27:

"SSP includes two models namely full model and short model for the calculation of "Safety Performance Index of Construction Sites".

Full model includes a whole list of 168 observable variables in 16 latent dimensions affecting Safety Performance.

Short model includes a short list of 48 observable variables in 16 latent dimensions affecting Safety Performance.

Please, click the model that you prefer to start. Short model predicts the Safety Performance with an acceptable accuracy and requires less time to complete."

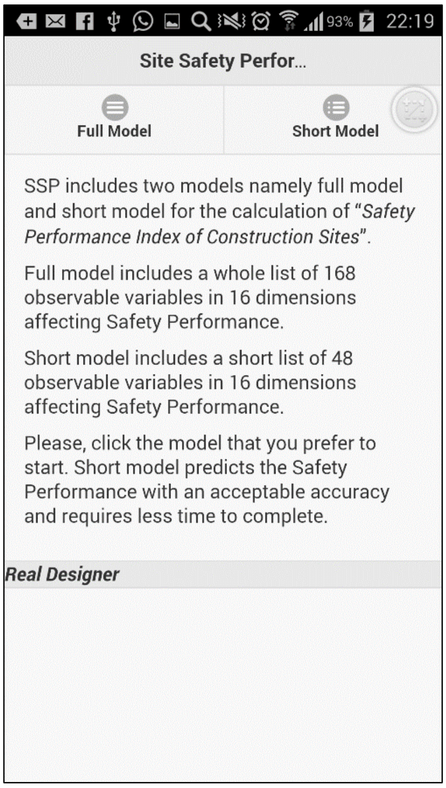


Figure 10.27: The model selection page of Site Safety Performance (SSP) mobile application

10.8.8 Full model page

When the full model button is triggered, the full model page is displayed on the screen. In the full model page of SSP mobile application, following explanations are made as seen in Figure 10.28 and Figure 10.29:

"Full model includes a whole list of 168 observable variables in 16 latent dimensions affecting Safety Performance.

Please evaluate the observable variables by using slider bars within a scale of 0-100 according to their conformity level at the construction site.

Evaluation of variables

(scale: 0-100)

0: Conformity is minimum.

100: Conformity is maximum.

NA: If not applicable.

After the evaluation, please click the results button to see the full model results of Safety Performance of the construction site."

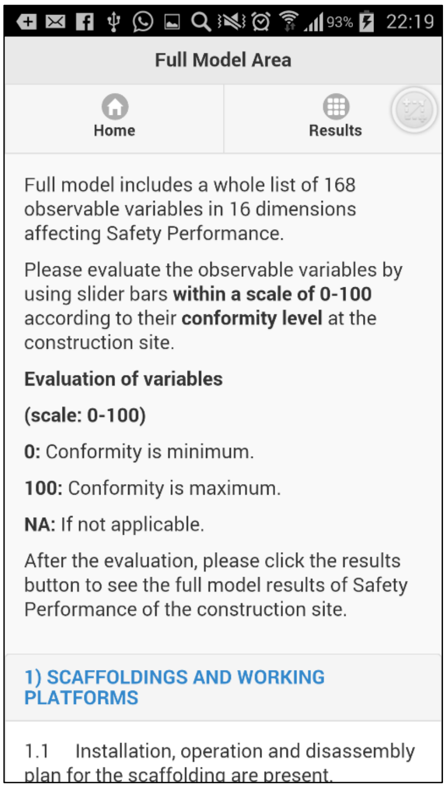


Figure 10.28: The full model page of Site Safety Performance (SSP) mobile application-1

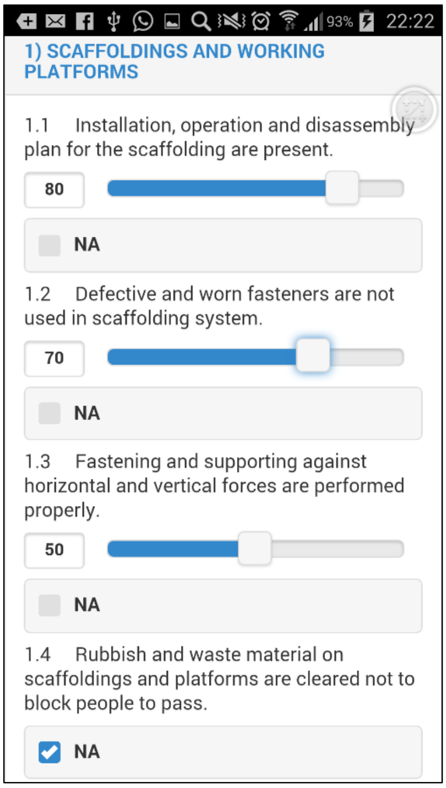


Figure 10.29: The full model page of Site Safety Performance (SSP) mobile application-2

10.8.9 Short model page

When the short model button is triggered, the short model page is displayed on the screen. In the short model page of SSP mobile application, following explanations are made as seen in Figure 10.30 and Figure 10.31:

"Short model includes a short list of 48 observable variables in 16 latent dimensions affecting Safety Performance.

Please evaluate the observable variables by using slider bars within a scale of 0-100 according to their conformity level at the construction site.

Evaluation of variables

(scale: 0-100)

0: Conformity is minimum.

100: Conformity is maximum.

NA: If not applicable.

After the evaluation, please click the results button to see the short model results of Safety Performance of the construction site."

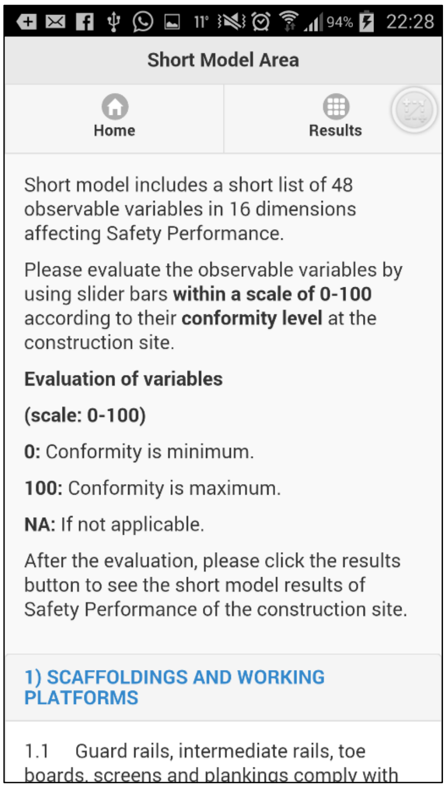


Figure 10.30: The short model page of Site Safety Performance (SSP) mobile application-1

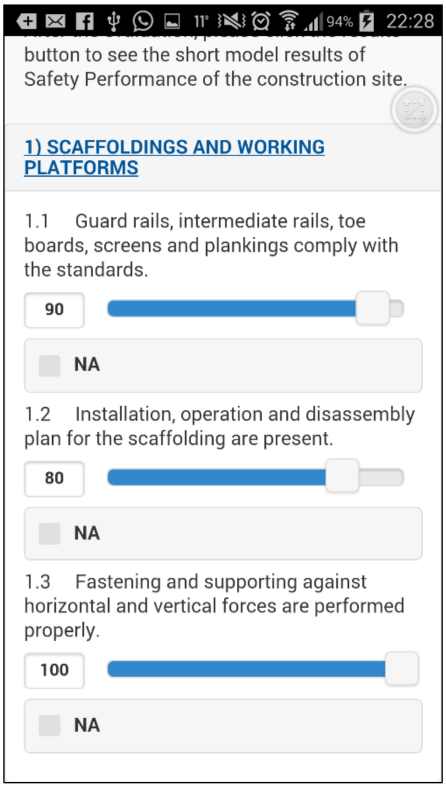


Figure 10.31: The short model page of Site Safety Performance (SSP) mobile application-2

10.8.10 Results page

Results page of full model:

When the results button is triggered in full model menu, the results page is displayed on the screen. In the results page of SSP mobile application, following explanations are made and results are demonstrated as seen in Figure 10.32 and Figure 10.33:

"This page demonstrates:

- *the entry values,*

- *calculated levels of each latent dimension affecting Safety Performance, and*
- *the result of Safety Performance Index of the construction site."*

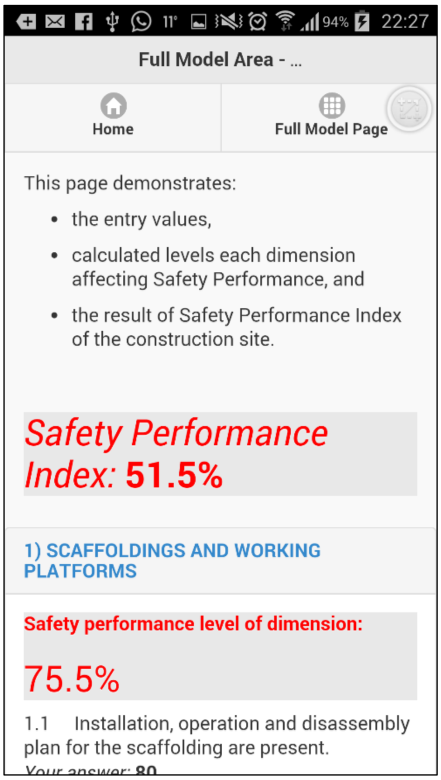


Figure 10.32: The results page of full model of SSP mobile application-1

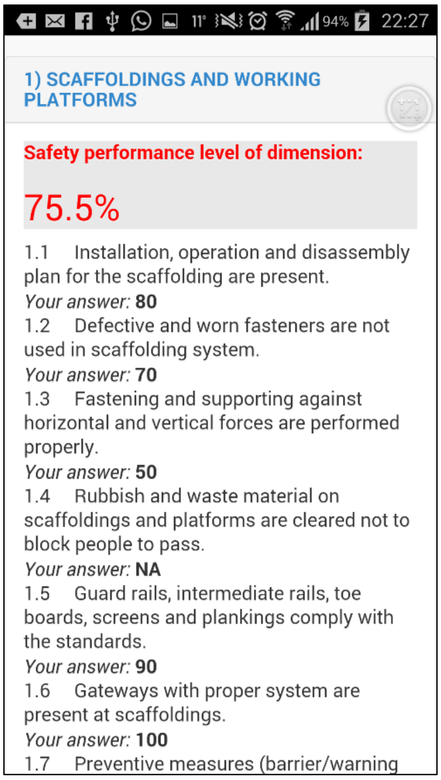


Figure 10.33: The results page of full model of SSP mobile application-2

Results page of short model:

When the results button is triggered in short model menu, the results page is displayed on the screen. In the results page of SSP mobile application, following explanations are made and results are demonstrated as seen in Figure 10.34 and Figure 10.35:

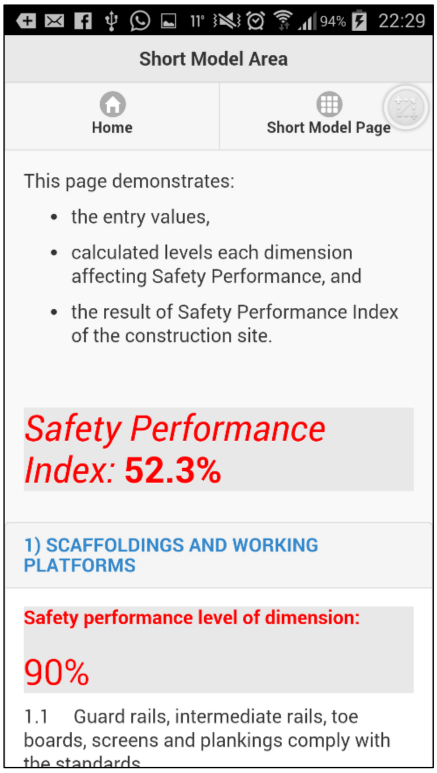


Figure 10.34: The results page of short model of SSP mobile application-1

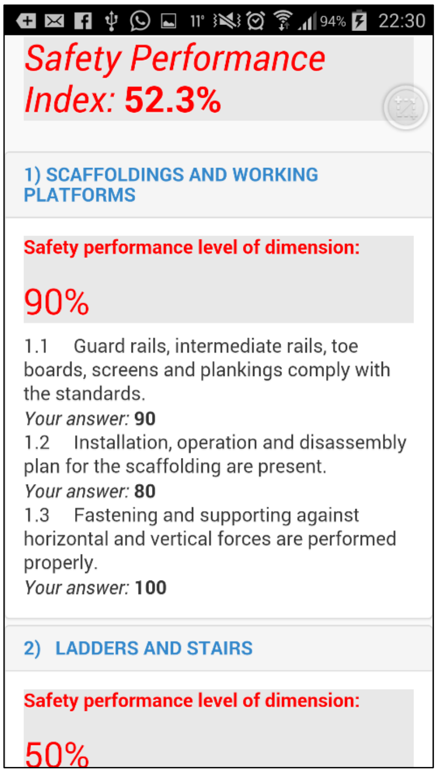


Figure 10.35: The results page of short model of SSP mobile application-2

10.8.11 Exit page

When back button is forced, program saves the data and closes down. If SSP mobile application is re-started, users can continue to make evaluation of the observable variables. SSP mobile application never expires. Data and results are always available, when a change is made in the evaluation of any observable variable, the results are calculated and changed accordingly and can be reached from results page simultaneously.

10.9 Conclusion

This chapter explained the development of a Site Safety Performance (SSP) web application software and SSP mobile application for mobile devices on a cross-platform. Brief information about mobile application categories namely native mobile, mobile-web and hybrid mobile applications was presented. Overall comparison between the three possible types of mobile applications was made. After giving basic information about HTML5, CSS3 and JavaScript languages in the coding the mobile application, the most widely used cross-platform Software Development Kits were presented. The development of a Site Safety Performance (SSP) web application software by using the HTML5, CSS3 and JavaScript coding languages was explained and the snapshots of the developed pages of the web application software were demonstrated.

Considering PhoneGap's advantages of being a standards-based, open source development framework, free to download, with community-built development tools and plugins (Karadimce and Bogatinoska 2014) and being the most popularly growing platform (VisionMobile 2013), in this study, PhoneGap was selected to develop a hybrid mobile application. The development procedure of the Site Safety Performance (SSP) application for mobile devices built on the previously developed SSP web application software by PhoneGap were explained. Snapshots of the application and its pages were demonstrated.

CHAPTER 11

DISCUSSION OF RESULTS AND RECOMMENDATIONS TO CONSTRUCTION SAFETY PROFESSIONALS

11.1 Introduction

In this chapter, the findings of the observed variables and latent dimensions affecting safety performance will be discussed and recommendations will be given to construction safety professionals to improve safety in construction sites.

11.2 Discussion about latent dimensions affecting "Safety Performance of Construction Sites" (SP)

According to the findings of this study, 16 latent dimensions affecting "safety performance of construction sites" with respect to their relative weights were listed in Table 11.1.

"Material handling (loading, transport, unloading, handling and storage)", "Traffic and transportation control" and "Welding works" were ranked as 1st latent dimension with relative weights of "0,0676". "Excavation works" and "Demolition works" were ranked as 4th latent dimensions with relative weights of "0,0669". "Lighting and electricity" was ranked as 6th latent dimension with a relative weight of "0,0654". "Hand/power tools, machinery and devices" was ranked as 7th latent dimension with a relative weight of "0,0647". "Working at height and protection against falling" and "Concrete and formwork" were ranked as 8th latent dimensions with relative weights of "0,0633". "Workers" was ranked as 10th latent dimension with a relative weight of "0,0618". "Housekeeping, order and tidiness" and "Personal protective equipment (PPE)" were ranked as 11th latent dimensions with relative weights of "0,0611". "Ladders and stairs" and "Fire prevention/protection" were ranked as 13th latent dimensions with a relative weight of "0,0597". "Scaffoldings and working platforms" was ranked as 15th latent dimension with a relative weight of "0,0568". Finally, "First aid" was ranked as 16th latent dimension with a relative weight of "0,0467".

Table 11.1: Relative weights of the latent dimensions of "Safety Performance of Construction Sites"

Abbreviation	**Latent Dimensions**	**Relative Weights**	**Rank**
G9	"Material handling (loading, transport, unloading, handling and storage)"	0,0676	1
G10	"Traffic and transportation control"	0,0676	1
G14	"Welding works"	0,0676	1
G12	"Excavation works"	0,0669	4
G15	"Demolition works"	0,0669	4
G4	"Lighting and electricity"	0,0654	6
G8	"Hand/power tools, machinery and devices"	0,0647	7
G3	"Working at height and protection against falling"	0,0633	8
G13	"Concrete and formwork"	0,0633	8
G16	"Workers"	0,0618	10
G5	"Housekeeping, order and tidiness"	0,0611	11
G6	"Personal protective equipment (PPE)"	0,0611	11
G2	"Ladders and stairs"	0,0597	13
G7	"Fire prevention/protection"	0,0597	13
G1	"Scaffoldings and working platforms"	0,0568	15
G11	"First aid"	0,0467	16
ALL LATENT DIMENSIONS		**1,0000**	

In the following parts, each dimension will be discussed separately. In this study, the relative effects of the observed variables to the Safety Performance of Construction Sites were calculated according to the formula below:

REj = **WDi** * **WOj**

Where:

- **REj** = Relative effect of the observed variable j to the "Safety Performance of Construction Sites",
- **WOj** = Relative weight of the observed variable $_j$ (refer to factor analysis results) = FLj / Σ (FLj)
- FLj = Factor loading of the observed variable $_j$
- **WDi=** Relative weight of latent dimension i of "Safety performance of construction sites" = (SPCDi) / Σ (SPCDi)
- SPCDi= Standardized path coefficient of the latent dimension i of "Safety performance of construction sites"
- Σ SPCDi= Summation of the standardized path coefficients of all latent dimensions of "Safety performance of construction sites"
- **i**= 1, 2, …, 16
- **j**= 1, 2, …., total number of observed variables in the corresponding latent dimension
- **Σ REj** = 1 (Total relative effect of 168 observed variables to the "Safety performance of construction sites" = 1)

As an example: In "Scaffoldings and working platforms" dimension, relative effect of the observed variable G1F5 to the "Safety Performance of Construction Sites" was calculated as 0,00518:

$$RE_{G1F5} = WD_1 * WO_{G1F5}$$
$$= 0{,}0568 * 0{,}0911$$
$$= \underline{0{,}00518}$$

11.3 Discussion about “Scaffoldings and working platforms” (G1)

As explained previously, “Scaffoldings and working platforms” dimension was ranked as 15^{th} with a relative weight of “0,0568”. In this latent dimension, rankings of the observed variables according to their relative effects to the “Safety Performance of Construction Sites” were given in Table 11.2. Top three of the observed variables most affecting the “safety performance of construction sites” were pointed out as:

1) *“Use of non-standard guard rails, intermediate rails, toe boards, screens and plankings” had a relative effect of “0,00518” and ranked as “139th” in total.*
2) *“Lack of installation, operation and disassembly plan for the scaffolding” had a relative effect of “0,00510” and ranked as “143th” in total.*
3) *“Improper fastening and supporting against horizontal and vertical forces” had a relative effect of “0,00503” and ranked as “147th” in total.*

Table 11.2: Ranking of the observed variables of "Scaffoldings and working platforms"

Observed Variable	Relative Weights	Rank in dimension	Relative Effect	Rank in Total
1) SCAFFOLDINGS AND WORKING PLATFORMS	**0,0568**			
1.5 Use of non-standard guard rails, intermediate rails, toe boards, screens and plankings	0,0911	1	0,00518	139
1.1 Lack of installation, operation and disassembly plan for the scaffolding	0,0899	2	0,00510	143
1.3 Improper fastening and supporting against horizontal and vertical forces	0,0886	3	0,00503	147
1.11 Assembly and disassembly by inexperienced people	0,0873	4	0,00496	150
1.2 Use of defective and worn fasteners in scaffolding system	0,0847	5	0,00481	154
1.6 Absence of gateways having proper system at scaffoldings	0,0847	5	0,00481	154
1.8 Failure to control before use	0,0834	7	0,00474	158
1.7 Failure to take preventive measures (barrier/warning notices) for incomplete/unsafe scaffolds	0,0822	8	0,00467	160
1.9 Failure to hang sign boards indicating the maximum load capacity that scaffoldings can bear at proper and visible places	0,0822	8	0,00467	160
1.12 Failure to use proper personal protective equipment (PPE)	0,0783	10	0,00445	165
1.4 Leaving rubbish and waste material on scaffoldings and platforms blocking people to pass	0,0745	11	0,00423	167
1.10 Overloading the scaffoldings and platforms	0,0732	12	0,00416	168

11.4 Discussion about "Ladders and stairs" (G2)

"Ladders and stairs" was ranked as 13^{th} with a relative weight of "0,0597". In this latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were shown in Table 11.3. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *"Failure to position at the correct angle" had a relative effect of "0,00688" and ranked as "22th" in total.*
2) *"Being improper for the job" had a relative effect of "0,00671" and ranked as "34th" in total.*
3) *"Use of equipment with damaged rungs, arms or connection parts" had a relative effect of "0,00645" and ranked as "50th" in total.*

Table 11.3: Ranking of the observed variables of “Ladders and stairs”

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
2) LADDERS AND STAIRS	**0,0597**			
2.7 Failure to position at the correct angle	0,1153	1	0,00688	22
2.6 Being improper for the job	0,1124	2	0,00671	34
2.2 Use of equipment with damaged rungs, arms or connection parts	0,1081	3	0,00645	50
2.3 Failure to base on firm and leveled foundation	0,1023	4	0,00611	67
2.5 Failure to tag ladders with missing parts	0,1009	5	0,00602	70
2.1 To be made of weak and defective material	0,0965	6	0,00576	94
2.4 Failure to fix bottom and top parts properly	0,0965	6	0,00576	94
2.9 Failure to position safe distances (Vehicles, mobile cranes and electricity lines etc.)	0,0965	6	0,00576	94
2.8 Failure to clean enough	0,0908	9	0,00542	122
2.10 Lack of daily inspection and maintenance	0,0807	10	0,00482	153

11.5 Discussion about “Working at height and protection against falling” (G3)

“Working at height and protection against falling” dimension was ranked as 8th with a relative weight of “0,0633”. In this latent dimension, rankings of the observed variables according to their relative effects to the “Safety Performance of Construction Sites” were shown in Table 11.4. Top three of the observed variables most affecting the “safety performance of construction sites” were:

1) *"Guardrails, handrails or rails not complying with standards" had a relative effect of "0,00803" and ranked as "3rd" in total.*
2) *"Lack of regular inspection and maintenance of safe working equipment used at heights" had a relative effect of "0,00782" and ranked as "4th" in total.*
3) *"Failure to use proper personal protective equipment (PPE)" had a relative effect of "0,00771" and ranked as "6th" in total.*

Table 11.4: Ranking of the observed variables of "Working at height and protection against falling"

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
3) WORKING AT HEIGHT AND PROTECTION AGAINST FALLING	**0,0633**			
3.4 Guardrails, handrails or rails not complying with standards	0,1269	1	0,00803	3
3.8 Lack of regular inspection and maintenance of safe working equipment used at heights	0,1235	2	0,00782	4
3.9 Failure to use proper personal protective equipment (PPE)	0,1219	3	0,00771	6
3.5 Employee's access to working places by inconvenient means and equipment	0,1152	4	0,00729	13
3.7 Failure to prevent access to the areas subject to falling objects or failure to erect covered gateways	0,1135	5	0,00719	14
3.6 Failure to take preventive measures against falling of hand tools and other materials	0,1068	6	0,00676	32
3.3 Safety nets and air bags not complying with standards	0,1018	7	0,00645	51
3.1 Failure to plan the work to be done in advance and failure to make the required organizations	0,1002	8	0,00634	58
3.2 Failure to place barrier and warning signs for open edges and holes	0,0902	9	0,00571	97

11.6 Discussion about "Lighting and electricity" (G4)

"Lighting and electricity" dimension was ranked as 6th with a relative weight of "0,0654". In this latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were shown in Table 11.5. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *"Failure to put the panels, boards, control apparatus, etc. into lockers or cabinets" had a relative effect of "0,00734" and ranked as "11th" in total.*
2) *"All of the hardware and connection work done by unauthorized people" had a relative effect of "0,00697" and ranked as "20th" in total.*
3) *"Failure to place electrical danger posts and warning signs" had a relative effect of "0,00687" and ranked as "23th" in total.*

Table 11.5: Ranking of the observed variables of “Lighting and electricity”

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
4) LIGHTING AND ELECTRICITY	**0,0654**			
4.5 Failure to put the panels, boards, control apparatus, etc. into lockers or cabinets	0,1122	1	0,00734	11
4.8 All of the hardware and connection work done by unauthorized people	0,1065	2	0,00697	20
4.9 Failure to place electrical danger posts and warning signs	0,1051	3	0,00687	23
4.6 Failure to enclose cabinets, panels and switches in weather-proof enclosures located in wet locations	0,1037	4	0,00678	27
4.7 Failure to mark overhead lines and failure to take appropriate measures to prevent contact	0,1023	5	0,00669	35
4.10 Failure to use proper personal protective equipment (PPE)	0,1023	5	0,00669	35
4.3 Use of improper connectors (E.g.: connections with open-ended cables)	0,0980	7	0,00641	52
4.4 Lack of utilization of proper residual current device in the main and secondary electricity panels	0,0980	7	0,00641	52
4.2 Lack of auxiliary illumination system against electricity cuts	0,0909	9	0,00595	78
4.1 Failure to supply adequate illumination for working places, passageways and routes	0,0810	10	0,00530	125

11.7 Discussion about "Housekeeping, order and tidiness" (G5)

"Housekeeping, order and tidiness" dimension was ranked as 11^{th} with a relative weight of "0,0611". In this latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were shown in Table 11.6. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *"The sanitary facilities are inadequate and failure to maintain the hygiene requirements" had a relative effect of "0,00557" and ranked as "107th" in total.*
2) *"Failure to perform measurement and control of harmful dusts, gases, fumes, vapors, vibration, noise, pollution" had a relative effect of "0,00529" and ranked as "126th" in total.*
3) *"Failure to take preventive measures (barriers/warning signs) for slippery surfaces" had a relative effect of "0,00522" and ranked as "134th" in total.*

Table 11.6: Ranking of the observed variables of "Housekeeping, order and tidiness"

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
5) HOUSEKEEPING, ORDER AND TIDINESS	**0,0611**			
5.8 The sanitary facilities are inadequate and failure to maintain the hygiene requirements	0,0911	1	0,00557	107
5.11 Failure to perform measurement and control of harmful dusts, gases, fumes, vapors, vibration, noise, pollution	0,0866	2	0,00529	126
5.4 Failure to take preventive measures (barriers/warning signs) for slippery surfaces	0,0854	3	0,00522	134
5.7 Failure to provide isolation tapes and warning notices for plant and equipment temporarily suspended for work execution	0,0854	3	0,00522	134
5.12 Failure to take necessary measures for protection of workers from too hot and cold	0,0854	3	0,00522	134
5.5 Lack of fencing the construction site properly to prevent unauthorized entry	0,0843	6	0,00515	141
5.3 Dumping the garbage negligently and failure to collect the garbage regularly	0,0831	7	0,00508	144
5.1 Lack of sufficient space for working areas	0,0820	8	0,00501	148
5.10 Failure to perform chemical and biological analyzes for potable water	0,0820	8	0,00501	148
5.9 Failure to provide sufficient amount of potable water	0,0797	10	0,00487	152
5.2 Failure to provide appropriate places where employees can relax	0,0786	11	0,00480	156
5.6 Leaving waste and materials with sharp and keen edges (E.g.: form with nails) in the working areas	0,0763	12	0,00466	162

11.8 Discussion about “Personal protective equipment (PPE)” (G6)

“Personal protective equipment (PPE)” dimension was ranked as 11th with a relative weight of “0,0611”. In this latent dimension, rankings of the observed variables according to their relative effects to the “Safety Performance of Construction Sites” were shown in Table 11.7. Top three of the observed variables most affecting the “safety performance of construction sites” were:

1) *“Failure to regularly maintain and clean” had a relative effect of “0,00730” and ranked as “12th” in total.*
2) *“Lack of inspection before each use” had a relative effect of “0,00713” and ranked as “15th” in total.*
3) *“Lack of having appropriate standards” had a relative effect of “0,00704” and ranked as “17th” in total.*

Table 11.7: Ranking of the observed variables of "Personal protective equipment (PPE)"

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
6) PERSONAL PROTECTIVE EQUIPMENT (PPE)	**0,0611**			
6.8 Failure to regularly maintain and clean	0,1195	1	0,00730	12
6.5 Lack of inspection before each use	0,1166	2	0,00713	15
6.1 Lack of having appropriate standards	0,1152	3	0,00704	17
6.7 Failure to provide adequate instruction and practical training for use and maintenance	0,1138	4	0,00695	21
6.2 Failure to access easily	0,1110	5	0,00678	30
6.3 Failure to provide adequate amounts	0,1110	5	0,00678	30
6.4 Lack of correct and proper use by workers	0,1081	7	0,00661	39
6.6 Use of equipment although it is damaged	0,1038	8	0,00634	56
6.9 Failure to encourage its use by means of signboard and posters	0,1010	9	0,00617	65

11.9 Discussion about "Fire prevention/protection" (G7)

"Fire prevention/protection" dimension was ranked as 13th with a relative weight of "0,0597". In this latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were shown in Table 11.8. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *"Lack of uninterrupted and adequate lighting system for emergency escape routes and exits" had a relative effect of "0,00653" and ranked as "42th" in total.*
2) *"Failure to display emergency plan, procedures, assembly points and emergency telephone numbers at visible positions" had a relative effect of "0,00645" and ranked as "48th" in total.*
3) *"Lack of proper alarm system clearly audible at all points on the site" had a relative effect of "0,00645" and ranked as "48th" in total.*

Table 11.8: Ranking of the observed variables of “Fire prevention/protection”

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
7) FIRE PREVENTION/PROTECTION	**0,0597**			
7.4 Lack of uninterrupted and adequate lighting system for emergency escape routes and exits	0,1094	1	0,00653	42
7.6 Failure to display emergency plan, procedures, assembly points and emergency telephone numbers at visible positions	0,1081	2	0,00645	48
7.8 Lack of proper alarm system clearly audible at all points on the site	0,1081	2	0,00645	48
7.9 Lack of regular inspection and maintenance of firefighting equipment, detectors and alarm systems	0,1055	4	0,00630	60
7.3 Lack of proper and permanent marking for emergency escape routes and exits	0,1016	5	0,00606	69
7.5 Existing obstacles in front of emergency escape routes and exits making difficult to quit	0,1003	6	0,00599	75
7.7 Lack of adequate/proper number and quality of fire detectors	0,1003	6	0,00599	75
7.2 Fire extinguishers are not easily accessible or obstacles are present in front of them	0,0911	8	0,00544	118
7.1 Lack of adequate number and proper type of fire extinguishers	0,0885	9	0,00529	129
7.10 Failure to conduct fire drill at regular intervals	0,0872	10	0,00521	138

11.10 Discussion about “Hand/power tools, machinery and devices” (G8)

“Hand/power tools, machinery and devices” dimension was ranked as 7th with a relative weight of “0,0647”. In this latent dimension, rankings of the observed variables according to their relative effects to the “Safety Performance of

Construction Sites" were shown in Table 11.9. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *"Use or operate in damaged condition" had a relative effect of "0,00570" and ranked as "98th" in total.*
2) *"Use or operate of tools, machines and devices without security protection inserted" had a relative effect of "0,00550" and ranked as "111th" in total.*
3) *"Lack of safe work instructions" had a relative effect of "0,00550" and ranked as "111th" in total.*

Table 11.9: Ranking of the observed variables of "Hand/power tools, machinery and devices"

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
8) HAND/POWER TOOLS, MACHINERY AND DEVICES	**0,0647**			
8.4 Use or operate in damaged condition	0,0882	1	0,00570	98
8.2 Use or operate of tools, machines and devices without security protection inserted	0,0849	2	0,00550	111
8.8 Lack of safe work instructions	0,0849	2	0,00550	111
8.11 Failure to position in safe distances (E.g.: people, materials, tools, excavation, slope, underground facility, soft ground, obstacles, electricity lines)	0,0849	2	0,00550	111
8.5 Use or operate by untrained and unauthorized operators	0,0839	5	0,00543	119
8.7 Lack of daily inspection and maintenance	0,0839	5	0,00543	119
8.12 Failure to use proper personal protective equipment (PPE)	0,0839	5	0,00543	119
8.9 Failure to clean enough	0,0828	8	0,00536	124
8.3 Use without making sure of the soundness of the floor and use without fixing	0,0817	9	0,00529	127
8.6 Lack of absence of a trained pointer to guide operator in necessary situations	0,0817	9	0,00529	127
8.1 Improper use and use for purposes other than it is intended	0,0806	11	0,00522	137
8.10 Failure to place barricades and warning signs when not in use	0,0785	12	0,00508	145

11.11 Discussion about "Material handling (loading, transport, unloading, handling and storage)" (G9)

"Material handling (loading, transport, unloading, handling and storage)" dimension was ranked as 1st with a relative weight of "0,0676". In this latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were shown in Table 11.10. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *"Absence of legible warning labels on hazardous materials and chemicals" had a relative effect of "0,00591" and ranked as "80th" in total.*
2) *"Lack of use of forwarding lines that guide loads" had a relative effect of "0,00584" and ranked as "83th" in total.*
3) *"Transportation by improper vehicles" had a relative effect of "0,00577" and ranked as "90th" in total.*

Table 11.10: Ranking of the observed variables of “Material handling (loading, transport, unloading, handling and storage)”

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
9) MATERIAL HANDLING (LOADING, TRANSPORT, UNLOADING, HANDLING AND STORAGE)	**0,0676**			
9.9 Absence of legible warning labels on hazardous materials and chemicals	0,0875	1	0,00591	80
9.6 Lack of use of forwarding lines that guide loads	0,0864	2	0,00584	83
9.2 Transportation by improper vehicles	0,0853	3	0,00577	90
9.3 Failure to comply with safe loading limitations	0,0853	3	0,00577	90
9.4 Loading/unloading/stacking by unsafe vehicles	0,0853	3	0,00577	90
9.10 Absence of Material safety data sheet (MSDS) belonging to hazardous materials and chemicals	0,0853	3	0,00577	90
9.5 Failure to design loading places and ramps according to dimensions of the load to be moved	0,0832	7	0,00562	103
9.8 Storage of hazardous materials and chemicals more than the allowed/exempted amount	0,0821	8	0,00555	108
9.7 Failure to remove/disposal of hazardous materials and chemicals by specially trained personnel	0,0810	9	0,00548	114
9.11 Failure to clearly display chemical hazard communication plan	0,0810	9	0,00548	114
9.12 Failure to use proper personal protective equipment (PPE)	0,0799	11	0,00540	123
9.1 Lack of proper planning	0,0778	12	0,00526	130

11.12 Discussion about "Traffic and transportation control" (G10)

"Traffic and transportation control" dimension was ranked as 1st with a relative weight of "0,0676". In this latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were shown in Table 11.11. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *"Roads with inadequate width" had a relative effect of "0,00659" and ranked as "40th" in total.*
2) *"Lack of adequate number of direction and warning signs" had a relative effect of "0,00651" and ranked as "46th" in total.*
3) *"Failure to keep adequate distance between roads (having vehicle traffic) and doors, gates, pedestrian passageways, corridors and stairs" had a relative effect of "0,00635" and ranked as "55th" in total.*

Table 11.11: Ranking of the observed variables of "Traffic and transportation control"

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
10) TRAFFIC AND TRANSPORTATION CONTROL	**0,0676**			
10.7 Roads with inadequate width	0,0975	1	0,00659	40
10.9 Lack of adequate number of direction and warning signs	0,0963	2	0,00651	46
10.8 Failure to keep adequate distance between roads (having vehicle traffic) and doors, gates, pedestrian passageways, corridors and stairs	0,0939	3	0,00635	55
10.12 Failure to take preventive measures against the entry of unauthorized people to prohibited areas	0,0916	4	0,00619	64
10.1 Lack of correct and regular inspection and maintenance of vehicles	0,0904	5	0,00611	66
10.11 Failure to take preventive measures against excavation material spillage and dust	0,0868	6	0,00587	81
10.6 Unclear routes	0,0809	7	0,00547	116
10.3 Driving vehicle without license	0,0773	8	0,00522	132
10.4 Driving vehicle without experience	0,0773	8	0,00522	132
10.5 Absence of proper and adequate first aid kit/fire extinguisher tube in vehicles	0,0749	10	0,00506	146
10.2 Failure to use safety belts	0,0678	11	0,00458	163
10.10 Failure to comply with speed limits	0,0654	12	0,00442	166

11.13 Discussion about “First aid” (G11)

“First aid” dimension was ranked as 16th with a relative weight of “0,0467”. In this latent dimension, rankings of the observed variables according to their relative effects to the “Safety Performance of Construction Sites” were shown in Table 11.12. Top three of the observed variables most affecting the “safety performance of construction sites” were:

1) *“Lack of easy to access first aid supplies and equipment” had a relative effect of “0,00662” and ranked as “38th” in total.*
2) *“Lack of adequate number of first aid supplies and equipment” had a relative effect of “0,00648” and ranked as “47th” in total.*
3) *“First aid supplies and equipment are not ready for use” had a relative effect of “0,00634” and ranked as “57th” in total.*

Table 11.12: Ranking of the observed variables of "First aid"

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
11) FIRST AID	**0,0467**			
11.4 Lack of easy to access first aid supplies and equipment.	0,1418	1	0,00662	38
11.3 Lack of adequate number of first aid supplies and equipment	0,1388	2	0,00648	47
11.5 First aid supplies and equipment are not ready for use	0,1358	3	0,00634	57
11.6 First aid supplies and equipment are not marked appropriately	0,1284	4	0,00599	74
11.2 Failure to display first aid staff and their contact information at visible positions	0,1209	5	0,00565	100
11.7 Lack of adequate number of emergency treatment rooms	0,1194	6	0,00558	106
11.1 Absence of trained first aid staff at site	0,1179	7	0,00551	110
11.8 Absence of on-site doctor	0,0970	8	0,00453	164

11.14 Discussion about "Excavation works" (G12)

"Excavation works" dimension was ranked as 4th with a relative weight of "0,0669". In this latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were shown in Table 11.13. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *"Use of unsafe entry and exit gates to access working area" had a relative effect of "0,00626" and ranked as "61th" in total.*

2) *"Inspection and control of excavation works by unauthorized people" had a relative effect of "0,00619" and ranked as "63th" in total.*
3) *"Performing night work without providing adequate lighting" had a relative effect of "0,00597" and ranked as "77th" in total.*

Table 11.13: Ranking of the observed variables of "Excavation works"

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
12) EXCAVATION WORKS	**0,0669**			
12.5 Use of unsafe entry and exit gates to access working area	0,0936	1	0,00626	61
12.1 Inspection and control of excavation works by unauthorized people	0,0925	2	0,00619	63
12.4 Performing night work without providing adequate lighting	0,0892	3	0,00597	77
12.7 Placing the materials improperly near to the excavation edges	0,0870	4	0,00582	84
12.11 Entry of unauthorized people to the excavation area	0,0870	4	0,00582	84
12.3 Failure to place proper barriers, railings and warning signs	0,0847	6	0,00567	99
12.12 Failure to use proper personal protective equipment (PPE)	0,0836	7	0,00559	104
12.9 Sloping the excavation area with improper angles	0,0825	8	0,00552	109
12.6 Failure to place secured stop blocks preventing the vehicles from falling into excavation area	0,0814	9	0,00544	117
12.2 Failure to locate beforehand underground facilities in excavation areas by using detectors, etc. (E.g.: cable, gas, water, sewer lines)	0,0769	10	0,00515	142
12.10 Performing excavation works while raining	0,0713	11	0,00477	157
12.8 Failure to support properly and adequately by performing static calculations of the excavation area (with slab, timber, trench boxes, shoring, lining, etc.)	0,0702	12	0,00470	159

11.15 Discussion about "Concrete and formwork" (G13)

"Concrete and formwork" dimension was ranked as 8^{th} with a relative weight of "0,0633". In this latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were shown in Table 11.14. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *"Failure to fix the concrete pump's supporting foots to the ground" had a relative effect of "0,00607" and ranked as "68th" in total.*
2) *"Use of weak and deformed forms" had a relative effect of "0,00600" and ranked as "72th" in total.*
3) *"Performing work directly below the concrete pouring area" had a relative effect of "0,00600" and ranked as "72th" in total.*

Table 11.14: Ranking of the observed variables of "Concrete and formwork"

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
13) CONCRETE AND FORMWORK	**0,0633**			
13.7 Failure to fix the concrete pump's supporting foots to the ground	0,0960	1	0,00607	68
13.3 Use of weak and deformed forms	0,0948	2	0,00600	72
13.10 Performing work directly below the concrete pouring area	0,0948	2	0,00600	72
13.8 Failure to take account of surrounding facilities while opening and closing pump handles	0,0936	4	0,00593	79
13.1 Failure to perform form works under the supervision of a competent person	0,0913	5	0,00578	86
13.2 Improper design and installation of form panels, supports and struts with respect to the loads on it	0,0913	5	0,00578	86
13.4 Use of ungrounded electrical vibrator	0,0913	5	0,00578	86
13.9 Operating the pump under energy transmission lines without taking precautions	0,0913	5	0,00578	86
13.6 Failure to position the concrete pump properly to the ground that concrete will be poured	0,0890	9	0,00563	101
13.11 Failure to use proper personal protective equipment (PPE)	0,0890	9	0,00563	101
13.5 Exposure of reinforcing bars	0,0775	11	0,00490	151

11.16 Discussion about "Welding works" (G14)

"Welding works" dimension was ranked as 1st with a relative weight of "0,0676". In this latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were shown in Table 11.15. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *"Welders without license and certificate" had a relative effect of "0,00755" and ranked as "9th" in total.*
2) *"Inadequate ventilation in narrow and confined areas" had a relative effect of "0,00711" and ranked as "16th" in total.*
3) *"Lack of daily control and maintenance of the welding equipment" had a relative effect of "0,00702" and ranked as "18th" in total.*

Table 11.15: Ranking of the observed variables of "Welding works"

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
14) WELDING WORKS	**0,0676**			
14.9 Welders without license and certificate	0,1117	1	0,00755	9
14.2 Inadequate ventilation in narrow and confined areas	0,1051	2	0,00711	16
14.1 Lack of daily control and maintenance of the welding equipment	0,1038	3	0,00702	18
14.10 Failure to use proper personal protective equipment (PPE)	0,1038	3	0,00702	18
14.7 Failure to take precautions against electrical and gas leakage	0,1012	5	0,00684	25
14.8 Use of deformed hoses	0,0999	6	0,00675	33
14.5 Failure to put adequate separation distance between fuels and oxygen	0,0986	7	0,00666	37
14.3 Failure to keep gas cylinders upright and failure to fasten in order not to overturn when shaked	0,0972	8	0,00657	41
14.4 Absence of proper type of fire extinguisher nearby	0,0920	9	0,00622	62
14.6 Contact oxygen tube with oily hand	0,0867	10	0,00586	82

11.17 Discussion about "Demolition works" (G15)

"Demolition works" dimension was ranked as 4th with a relative weight of "0,0669". In this latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were shown in Table 11.16. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *“Failure to enclose the demolition area and failure to place warning signs” had a relative effect of “0,00852” and ranked as “1st” in total.*
2) *“Performing demolition works under the supervision of an incompetent person” had a relative effect of “0,00820” and ranked as “2nd” in total.*
3) *“Failure to use proper personal protective equipment (PPE)” had a relative effect of “0,00778” and ranked as “5th” in total.*

Table 11.16: Ranking of the observed variables of “Demolition works”

Observed Variable	**Relative Weights**	**Rank in Dimension**	**Relative Effect**	**Rank in Total**
15) DEMOLITION WORKS	**0,0669**			
15.2 Failure to enclose the demolition area and failure to place warning signs	0,1274	1	0,00852	1
15.4 Performing demolition works under the supervision of an incompetent person	0,1226	2	0,00820	2
15.9 Failure to use proper personal protective equipment	0,1164	3	0,00778	5
15.1 Lack of preparation and planning of actions before the start of demolition works	0,1148	4	0,00768	7
15.5 Failure to remove people, vehicles, materials and equipment enough from the demolition area	0,1132	5	0,00757	8
15.3 Failure to take existing service lines (gas, water, electricity lines, etc.) under control or failure to cut whereas necessary	0,1116	6	0,00747	10
15.7 Failure to transport materials and ruins in a systematical and secured way	0,1022	7	0,00684	26
15.8 Failure to perform asbestos powder measurement for structures that may contain asbestos	0,0975	8	0,00652	45
15.6 Failure to take necessary precautions to avoid dust during demolition	0,0943	9	0,00631	59

11.18 Discussion about "Workers" (G16)

"Workers" dimension was ranked as 10th with a relative weight of "0,0618". In this latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were shown in Table 11.17. Top three of the observed variables most affecting the "safety performance of construction sites" were:

1) *"Performing erroneous methods and applications" had a relative effect of "0,00687" and ranked as "24th" in total.*
2) *"Taking the apparent risks" had a relative effect of "0,00678" and ranked as "28th" in total.*
3) *"Lacking safety consciousness" had a relative effect of "0,00678" and ranked as "28th" in total.*

Table 11.17: Ranking of the observed variables of "Workers"

Observed Variable	Relative Weights	Rank in Dimension	Relative Effect	Rank in Total
16) WORKERS	**0,0618**			
16.3 Performing erroneous methods and applications	0,1111	1	0,00687	24
16.2 Taking the apparent risks	0,1097	2	0,00678	28
16.5 Lacking safety consciousness	0,1097	2	0,00678	28
16.4 Working without plan and cautiousness	0,1056	4	0,00652	43
16.7 Working without permission	0,1056	4	0,00652	43
16.10 Inadequacy of safety trainings	0,1028	6	0,00635	54
16.1 Avoiding the use of personal protective equipment intentionally	0,0972	7	0,00601	71
16.6 Working without morale	0,0903	8	0,00558	105
16.9 The continuous change of workers (Personnel turnover rate is high)	0,0847	9	0,00524	131
16.8 Use of alcohol and drug	0,0833	10	0,00515	140

11.19 Recommendations to safety professionals

Top 30 of the observed variables most affecting the "safety performance of construction sites" were shown in Table 11.18.

Table 11.18: Top 30 of the observed variables most affecting the "safety performance of construction sites"

Observed Variable	Latent Dimension	Relative Effect	Rank in Total
G15F2 Failure to enclose the demolition area and failure to place warning signs	Demolition works	0,00852	1
G15F4 Performing demolition works under the supervision of an incompetent person	Demolition works	0,00820	2
G3F4 Guardrails, handrails or rails not complying with standards	Working at height and protection against falling	0,00803	3
G3F8 Lack of regular inspection and maintenance of safe working equipment used at heights	Working at height and protection against falling	0,00782	4
G15F9 Failure to use proper personal protective equipment (PPE)	Demolition works	0,00778	5
G3F9 Failure to use proper personal protective equipment (PPE)	Working at height and protection against falling	0,00771	6
G15F1 Lack of preparation and planning of actions before the start of demolition works	Demolition works	0,00768	7
G15F5 Failure to remove people, vehicles, materials and equipment enough from the demolition area	Demolition works	0,00757	8
G14F9 Welders without license and certificate	Welding works	0,00755	9
G15F3 Failure to take existing service lines (gas, water, electricity lines, etc.) under control or failure to cut whereas necessary	Demolition works	0,00747	10
G4F5 Failure to put the panels, boards, control apparatus, etc. into lockers or cabinets	Lighting and electricity	0,00734	11
G6F8 Failure to regularly maintain and clean	Personal protective equipment (PPE)	0,00730	12
G3F5 Employee's access to working places by inconvenient means and equipment	Working at height and protection against falling	0,00729	13
G3F7 Failure to prevent access to the areas subject to falling objects or failure to erect covered gateways	Working at height and protection against falling	0,00719	14
G6F5 Lack of inspection before each use	Personal protective equipment (PPE)	0,00713	15

Table 11.18: Top 30 of the observed variables most affecting the "safety performance of construction sites" (Cont'd)

Observed Variable	**Latent Dimension**	**Relative Effect**	**Rank in Total**
G14F2 Inadequate ventilation in narrow and confined areas	Welding works	0,00711	16
G6F1 Lack of having appropriate standards	Personal protective equipment (PPE)	0,00704	17
G14F1 Lack of daily control and maintenance of the welding equipment	Welding works	0,00702	18
G14F10 Failure to use proper personal protective equipment (PPE)	Welding works	0,00702	18
G4F8 All of the hardware and connection work done by unauthorized people	Lighting and electricity	0,00697	20
G6F7 Failure to provide adequate instruction and practical training for use and maintenance	Personal protective equipment (PPE)	0,00695	21
G2F7 Failure to position at the correct angle	Ladders and stairs	0,00688	22
G4F9 Failure to place electrical danger posts and warning signs	Lighting and electricity	0,00687	23
G16F3 Performing erroneous methods and applications	Workers	0,00687	24
G14F7 Failure to take precautions against electrical and gas leakage	Welding works	0,00684	25
G15F7 Failure to transport materials and ruins in a systematical and secured way	Demolition works	0,00684	26
G4F6 Failure to enclose cabinets, panels and switches in weather-proof enclosures located in wet locations	Lighting and electricity	0,00678	27
G16F2 Taking the apparent risks	Workers	0,00678	28
G16F5 Lacking safety consciousness	Workers	0,00678	28
G6F2 Failure to access easily	Personal protective equipment (PPE)	0,00678	30
G6F3 Failure to provide adequate amounts	Personal protective equipment (PPE)	0,00678	30

According to the preceding findings, the following recommendations to construction safety professionals were provided to improve the safety performance of construction sites. Full list of 168 recommendations were presented in Appendix J.

30 Recommendations to Construction Safety Professionals:

1) *Demolition area should be enclosed and warning signs should be placed.*
2) *Demolition works should be performed under the supervision of competent person.*
3) *Guardrails, handrails or rails should comply with the standards.*
4) *Safe working equipment used at heights should be regularly inspected and maintained.*
5) *Proper personal protective equipment (PPE) should be used during demolition works.*
6) *Proper personal protective equipment (PPE) should be used while working at height to protect against falling.*
7) *Preparation and planning of actions should be performed before the start of demolition works.*
8) *People, vehicles, materials and equipment should be removed enough from the demolition area.*
9) *Welders should possess license/certificate.*
10) *Existing service lines (gas, water, electricity lines, etc.) should be taken under control or cut where necessary.*
11) *Panels, boards, control apparatus, etc. should be stored in lockers or cabinets.*
12) *Personal protective equipments should be regularly maintained and kept clean.*
13) *Employee's access to working places located at heights by inconvenient means and equipment should be restricted.*

14) *Access to the areas subject to falling objects should be prevented and gateways with coverings should be erected.*
15) *Personal protective equipments should be inspected before each use.*
16) *Adequate ventilation should be supplied to narrow and confined areas for welding works.*
17) *Personal protective equipments should have appropriate standards.*
18) *Welding equipments should be inspected/controlled daily and maintained.*
19) *Proper personal protective equipment (PPE) should be used during welding works.*
20) *All of the hardware and connection works should be done by authorized people.*
21) *Adequate instruction and practical training should be provided to workers for use and maintenance of personal protective equipment (PPE).*
22) *Ladders should be positioned at the correct angle.*
23) *Electrical danger posts and warning signs should be present.*
24) *Workers should perform correct methods and applications.*
25) *Necessary precautions should be taken against electrical and gas leakage during welding works.*
26) *Materials and ruins should be transported in a systematical and secured way during demolition works.*
27) *Cabinets, panels and switches located in wet locations should be enclosed with weather-proof enclosures.*
28) *Workers should not take the apparent risks.*
29) *Workers should have safety consciousness.*
30) *Workers should access personal protective equipments easily and adequate amounts of personal protective equipments should be provided.*

11.20 Chapter summary

In this chapter, the findings of the observed variables and latent dimensions affecting safety performance was discussed. 16 latent dimensions affecting safety performance of construction sites were mentioned with respect to their relative weights. In the following parts, each dimension was discussed separately. Relative effects of the observed variables to the "safety performance of construction sites" was calculated. In each latent dimension, rankings of the observed variables according to their relative effects to the "safety performance of construction sites" were given. In each latent dimension, top three of the observed variables most affecting the "safety performance of construction sites" were mentioned.

Top 30 of the observed variables most affecting the "safety performance of construction sites" were discussed and recommendations to construction safety professionals were provided to improve the safety performance of construction sites. A full list of 168 recommendations were presented in Appendix J.

CHAPTER 12

CONCLUSIONS AND RECOMMENDATIONS

12.1 Conclusions

Safety plays a vital role in construction especially since the sector is generally more hazardous than any other industries due to the use of heavy equipment, dangerous tools, constantly changing work environment and hazardous materials, all of which increase the potential for serious accidents and injuries (Metinsoy 2010). Despite improvements over the years, accidents and injuries continue to plague the construction industry (Zhou et al. 2015).

This study focused on developing and validating a multidimensional safety performance model for construction sites. The significance of this study was that it firstly planned to develop an empirically validated theoretical model; then, based on this model, a safety performance index assessment software tool was proposed to improve the construction safety.

The principal aim of this study was to examine the relationships between determinants (observable variables and latent dimensions) of safety performance in construction sites. A multidimensional safety performance model was developed such that the safety performance determinants were empirically validated and the relationships between the determinants were justified. Based on the empirically validated theoretical model, a safety performance index assessment tool was proposed by developing a site safety performance application for mobile devices.

There were nine (9) objectives of this study which have been achieved in previous chapters.

The *first* objective was to identify the observable variables of safety performance of construction sites. In Chapter 2, through detailed literature review, expert opinions and face-to-face interviews with 15 construction safety professionals a total number of 168 observable variables were identified.

The *second* objective was to identify the latent dimensions affecting safety performance of construction sites. In Chapter 2, through detailed literature review, expert opinions and face-to-face interviews with 15 construction safety professionals a total number of 16 latent dimensions were identified.

The *third* objective was to study the relationships between determinants (observed variables and latent dimensions) of safety performance of construction sites. In Chapter 4, a final questionnaire form was developed and administered to the construction professionals having considerable experience in construction sites. As a result of the questionnaire survey, 180 full responses (Out of 1029 responses) were successfully achieved. In Chapter 5, the data, collected from respondents by linguistic terms as "low, medium, high" for variables affecting "Safety Performance of Construction Sites", were defuzzified into concrete numbers by using fuzzy set theory. In Chapter 6, a final safety performance model have been formed and the research hypotheses have been determined regarding the determinants collected together previously. In Chapter 7, in-depth statistical analysis of the acquired data were explained. In Chapter 8, after having described the preparation of the analyses for SEM, the assessment of the measurement model by SEM was presented inclusive of content validity, unidimensionality, convergent validity, goodness of fit, reliability (internal consistency and composite reliability), and discriminant validity testings. Analysis of the measurement model was carried out using factor analysis by first-order and second-order confirmatory factor analysis (CFA) for the assessment of unidimensionality, convergent validity, reliability, and discriminant validity. After achieving the validity of the measurement model, the assessment of the structural model including the testing of hypothesized second-order factor structural model by structural equation modeling (SEM) as a confirmatory assessment of structural validity, and the testing of the research hypotheses were explained comprehensively. Hypothesis testing results showed that, all of the research hypotheses were supported. It was found that 16 latent dimensions had positive and direct effects on “Safety performance of construction sites”.

The *fourth* objective was to develop and validate a multidimensional safety performance model. In Chapter 8, analysis and development of a multidimensional safety performance model for construction sites by Structural Equation Modeling (SEM) was achieved. The assessment of the measurement model by SEM was presented inclusive of content validity, unidimensionality, convergent validity, goodness of fit, reliability (internal consistency and composite reliability), and discriminant validity testings. Analysis of the measurement model was carried out using factor analysis by first-order and second-order confirmatory factor analysis (CFA) for the assessment of unidimensionality, convergent validity, reliability, and discriminant validity. After achieving the validity of the measurement model, the equations calculated by LISREL corresponding to the measurement model (associations between the latent variables and respective observable variables) and the structural model (associations between first-order and second-order latent variables) were presented. Finally, the assessment of the structural model including the testing of hypothesized second-order factor structural model by structural equation modeling (SEM) as a confirmatory assessment of structural validity, and the testing of the research hypotheses were explained comprehensively. Hypothesis testing results showed that, all of the research hypotheses were supported and validation of the developed multidimensional safety performance model was satisfied.

The *fifth* objective was to develop the formulation of the Safety Performance Index of Construction Sites. In Chapter 9, the development of the Safety Performance Index assessment tool with the adopted methodology from Yoo and Donthu (2001) and Avcılar (2010) was presented. The relative weights of the 16 different latent dimensions of "Safety Performance of construction sites" were calculated according to the standardized path coefficients of 16 latent dimensions affecting "SP". Factor loadings of the observed variables, relative weights of the observed variables, updated relative weights of the observed variables, site evaluations of the observed variables, the cumulative weighted mean of the site observations of each latent dimension, standardized path coefficients of the latent dimensions, relative weights of the latent dimensions, updated relative weights of the latent dimensions, Safety Performance Indices of construction sites utilized in the formula were explained. The formulation of the Safety Performance Index of construction sites was developed.

The *sixth* objective was to conduct case studies in international construction sites and perform assessment of their safety performance indices and benchmark the results. In Chapter 9, Case studies were conducted at 11 international construction sites to assess their safety performance indices. Investigations were made and evaluation forms (including the full list of 168 observed variables in 16 latent dimensions of safety performance) were filled (taking into account of a scale between 0 to 100, where 0: Conformity is minimum, 100: Conformity is maximum, NA: If not applicable) at the construction sites by safety engineers of the companies working for the Case study projects. For all of the 11 Case studies; the Site Safety Performance Indices and the safety performance level of each 16 latent dimensions were calculated. For illustration purpose, detailed information regarding the calculation of the Site Safety Performance Index of Case study #1 was given and the items utilized in the formula were explained. Possible scenarios and their reflection to the developed formula were explained. Then, in each Case study, Safety performance levels of latent dimensions in descending order were shown in tables and figures. The Site Safety Performance Indices of

11 Case studies were benchmarked and results were demonstrated in descending order.

The *seventh* objective was to develop a short (simple) model as an alternative to the full model to assess safety performance ensuring simplicity, fastness and reasonable accuracy. In Chapter 9, a proposal of a short (simple) model (48 observed variables in 16 latent dimensions) as an alternative to the full model (168 observed variables in 16 latent dimensions) was explained. Results of safety performance by the short (simple) model and the full model were compared for Case studies #1 to #11. Deviations of the results of the short model from the results of the full model were calculated. The average deviation of the short model results from full model results was found to be + 3,14%, smaller than 5%, therefore it was found quite reasonable to utilize the proposed short model taking the advantages of its simplicity, fastness and reasonable accuracy.

The *eighth* objective was to propose a safety performance index assessment software tool for construction sites by developing a site safety performance (SSP) software and an application for mobile devices based on the empirically validated theoretical model. Chapter 10 explained the development of a Site Safety Performance (SSP) web application software and SSP mobile application for mobile devices on a cross-platform. Brief information about mobile application categories namely native mobile, mobile-web and hybrid mobile applications were presented. Overall comparison between the three possible types of mobile applications was made. After giving basic information about HTML5, CSS3 and JavaScript languages in the coding the mobile application, the most widely used cross-platform Software Development Kits were presented. The development of a Site Safety Performance (SSP) web application software by using the HTML5, CSS3 and JavaScript coding languages was explained and the snapshots of the developed pages of the web application software were demonstrated. Considering PhoneGap's advantages of being a standards-based, open source development framework, free to download, with community-built development tools and plugins (Karadimce and Bogatinoska 2014) and being the most popularly growing platform (VisionMobile 2013), in this study, PhoneGap was selected to develop a hybrid mobile application. The development procedure of the Site Safety Performance (SSP) application for mobile devices built on the previously developed SSP web application software by PhoneGap were explained. Snapshots of the application and its pages were demonstrated.

The *ninth* objective was to discuss and point out top 30 of the observed variables most affecting the "safety performance of construction sites" and provide recommendations to construction safety professionals. Chapter 11 discussed the findings of the observed variables and latent dimensions affecting safety performance. 16 latent dimensions affecting safety performance of construction sites were mentioned with respect to their relative weights. Each dimension was discussed separately. Relative effects of the observed variables to the Safety Performance of Construction Sites was calculated. In each latent dimension, rankings of the observed variables according to their relative effects to the "Safety Performance of Construction Sites" were given. In each latent dimension, top three of the observed variables most affecting the "safety performance of construction sites" were mentioned. Top 30 of the observed variables most affecting the "safety performance of construction sites" were discussed and recommendations to construction safety professionals were provided to improve the safety performance of construction sites. A full list of 168 recommendations were presented.

This study adopted a novel approach and represented a safety performance index assessment tool for construction sites based on the empirically validated theoretical model. In this study, an integrated approach was adopted to incorporate fuzzy set theory into structural equation modeling technique to the collection and analysis of the research data.

An exploratory sequential design method, a sequential mixed method in research design, was implemented, starting with qualitative data collection and analysis phase followed by quantitative data collection and analysis phase, built on former phase to test qualitative exploratory findings.

The linguistic terms were defuzzified into concrete numbers by fuzzy set theory which provides strong and significant instruments for the measurement of ambiguities and provides the opportunity to meaningfully represent ambiguous concepts expressed in the natural language. Fuzzy theory is based upon uncertainties where there is an inherent impreciseness and it provides mathematical tools to deal with imprecise, uncertain, and vague data. The form of Mamdani-style fuzzy rules (Mamdani and Assilian 1975) was implemented due to the advantages of the Mamdani's approach, being the most popular in the literature, also being intuitive, having widespread acceptance, and well-suited to human input (Kaur and Kaur 2012).

Structural equation modeling, a quite strong multivariable analysis technique making possible the evaluation of latent structures, was used as a research analysis tool. Structural equation modeling was selected as an analysis and testing tool for the current study due to its unique features over other multivariate techniques. The validity of the hypotheses and proposed model were tested by using structural equation modeling based on the collected data. Although there were other statistical packages that could be used to analyze structural equation models, LISREL was selected for the current study in the analysis and testing of the proposed structural equation model after comparing various commercially available structural equation modeling software packages according to their observed analysis capabilities and popularity of use in the literature. Maximum likelihood (ML) was the selected as the estimation technique considering that ML is the default estimation method in most statistical packages and the more widely used estimation method, ML is quite consistent at producing efficient estimation and ML is rather robust against moderate violations of the normality assumption, provided that the sample comprises 100 or more observations. Conforming the Anderson and Gerbing’s (1988) two-step approach for structural equation modeling, the measurement model was analyzed separately and prior to the analysis of the structural model, taking advantage of its allowance for unidimensionality assessments.

The average deviation of the short model results from full model result was calculated as + 3,14%. Since the average deviation was smaller than 5%, it was found to be quite reasonable to utilize the proposed short model taking into account its simplicity, fastness and reasonable accuracy.

According to the results, the highest safety performance index in all the cases is calculated as 91,58% for Case study 11, whereas the lowest safety performance index is calculated as 35,92% for Case study 7. The high number of near miss cases/incidents/accidents, and low-conformity of the safety dimensions in Case study 7 reasonably explains and supports this remarkable difference in site safety performance between these two cases.

12.2 Recommendations for future study

Future studies can be designed by utilizing different model parameters such as: different number of observable variables and latent dimensions, linguistic variables and membership functions, fuzzy rules, aggregation and defuzzification methods, estimating techniques.

In this study, the evaluation forms (including the full list of 168 observed variables in 16 latent dimensions of safety performance) were filled at the construction sites by safety engineers of the companies working for the Case study projects taking into account of a scale between 0 to 100, where 0: Conformity is minimum, 100: Conformity is maximum, NA: If not applicable. It was assumed that, safety engineers had considerable experience and knowledge in construction site safety in evaluating the forms. But in the real life, it is advisable that, to assure the calibration among evaluators, future studies shall develop user manuals explaining how to evaluate observed variables occurring at the site in a scale between 0 and 100. This will result in a better calibration amongst the evaluators which can enhance the quality of the results of different sites and different projects.

Cloud-support can be integrated to the developed mobile applications to save the results online servers and make available from everywhere to reach the benchmarking of the safety performance results of different sites in different projects effectively.

This thesis opens up possibilities where future researchers can produce more powerful, versatile and user friendly softwares that can produce fast and reliable results.

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APPENDIX A

THE PRELIMINARY QUESTIONNAIRE FORM

Questionnaire Survey: Importance level of factors affecting Safety Performance of construction sites

Dear Participant,
This questionnarie form has been prepared in the scope of an ongoing PHd thesis study "A Fuzzy Structural Equation Model to Analyze Relationships Between Determinants of Safety Performance in Construction Sites: Development of a Safety Performance Index Assessment Tool" in the Department of Civil Engineering at Middle East Technical University. Filling the questionnaire form will take a part of your valuable time without doubt. However, we strongly wish you help us with filling out the survey to increase consciousness in safety.

Collected information will absolutely be kept confidential. Thanks for your kind support and we wish you good luck. Sincerely yours,

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* Required

Part-1: General Information

Dear Participant;

This part consists of questions regarding you and the company you are working for. Please select the suitable choices / fill in the blanks.

1. **Which sector are you working for?** *
   Check all that apply.
   - [ ] Public
   - [ ] Private
   - [ ] Other: ....

2. **Which party are you working for?** *
   Check all that apply.
   - [ ] Owner
   - [ ] Contractor
   - [ ] Consultant
   - [ ] Other: ....

3. **What is your position at your company?** *

Check all that apply.

- [ ] Owner
- [ ] Manager
- [ ] Engineer-Supervisor
- [ ] Technician-Foreman
- [ ] Other: ____________________

4. **Do you own occupational safety expertise sertificate?** *

Check all that apply.

- [ ] No
- [ ] Yes, Class A
- [ ] Yes, Class B
- [ ] Yes, Class C

5. **Areas of expertise of company you work for.** *

Check all that apply.

- [ ] Building construction
- [ ] Transport
- [ ] Infrastructure
- [ ] Hydraulic structures
- [ ] Industrial facilities
- [ ] Other: ____________________

6. **How many years have you been working for this company?** *

____

7. **How many years have you been working in construction industry?** *

____

Part-2: Safety Performance Model

Dear Participant;

16 groups and 98 factors affecting Safety Performance of Construction Sites are listed below.

Please, select the suitable expression checkbox next to groups and factors by taking into account their Importance Level on "Safety Performance of Construction Sites".

8. **Group 1: Working habits of workers** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Workers are routinized using the required personal protective equipment / safety equipment correctly (e.g., correct use of helmets, use of ear and eye protection equipment, use of welding goggles).					
2. Workers are not taking (avoiding) any obvious risk.					
3. Workers are having safe positions/actions/practices.					
4. Workers are avoiding reckless action.					
5. Workers are having safety consciousness.					

9. **Group 2: Scaffoldings and working platforms** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Scaffolds are of good/proper construction, made of strong and sound materials and properly maintained.					
2. Scaffolds are adequately fixed, secured, tied, braced, founded and cleaned by competent person.					
3. Safe means of access to scaffolds, such as proper ladders, stairs are provided.					
4. Guard rails, intermediate rails, toe boards, screens and plankings are adequately provided and fitted at working platforms.					
5. Effective barriers or warning notices are indicated for incomplete or unsafe scaffolds.					
6. Scaffolds are inspected periodically and inspection forms are recorded.					

10. **Group 3: Ladders and stairs** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Ladders/stairs are in good condition, made of strong and sound material, inspected and checked for defects before use.	⬭	⬭	⬭	⬭	⬭
2. Ladders/stairs have level and firm footings.	⬭	⬭	⬭	⬭	⬭
3. Ladders/stairs are secured against slipping, sliding or falling.	⬭	⬭	⬭	⬭	⬭
4. Ladders/stairs are placed in a safe place away from moving vehicles, overhead cranes or electricity lines.	⬭	⬭	⬭	⬭	⬭
5. Ladders/stairs with split or missing rungs are taken out of service.	⬭	⬭	⬭	⬭	⬭

11. **Group 4: Hand/power tools, machines, equipment and devices** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Hand/power tools, machines, equipment and devices are used properly for the job and within the load limitations.	⬭	⬭	⬭	⬭	⬭
2. Appropriate safety guards are fitted to hand/power tools, machines, equipment and devices.	⬭	⬭	⬭	⬭	⬭
3. Hand/power tools, machines, equipment and devices are in good condition, are regularly checked/inspected and have maintenance logs recorded	⬭	⬭	⬭	⬭	⬭

logs recorded including the date of their repair and have up-to-date test certificates issued by competent authority.					
4. Hand/power tools, machines, equipment and devices are operated by trained/licensed personnel only, slingers/banksmen are appointed, adequately trained and assigned as the only persons entitled to give signals to operators, and operator logs are up to date.					
5. Hand/power tools, machines, equipment and devices are stored in safe condition at idle time.					
6. Hand/power tools, machines, equipment and devices are in a safe distance from people, materials, vehicles, excavations, slopes, underground services, soft grounds, obstructions, power lines, etc. (e.g., power lines are de-energized, removed or relocated at a safe distance) and barricades /warning signs are put in place.					
7. Lifting devices are firmly leveled to base and material to be lifted is firmly supported and outriggers are used if needed.					

12. **Group 5: Protection against falling** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Workers working at low levels are protected from falling objects (e.g., using personal protective equipment).	⬭	⬭	⬭	⬭	⬭
2. Open edges and holes are clearly marked to guard against falls of people and materials.	⬭	⬭	⬭	⬭	⬭
3. Floor & roof openings, platforms, stairways and runways are equipped with proper railings, handrails, guardrails and covers.	⬭	⬭	⬭	⬭	⬭
4. Proper personal fall arrest systems and safety nets are used.	⬭	⬭	⬭	⬭	⬭

13. **Group 6: Lighting and electricity** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Adequate illumination is supplied at workplace/passageways/routes.					
2. Leads, cords, cables and plugs are free from damage and wirings are adequate, well insulated, and properly grounded.					
3. Cabinets, panels and switches located in wet locations are enclosed in weather proof enclosures.					
4. Overhead lines are identified and appropriate measures are taken such as removing, diverting or marking the lines to prevent contact.					
5. Electrical tools and equipment are inspected, tested and documented by competent personnel according to their testing regime.					
6. Electrical danger posts and warning signs are present.					

14. **Group 7: Housekeeping, order and tidiness** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Working areas are clear of tripping hazards, accesses to routes are free from obstruction and adequate width and appropriate signage is provided.	⬭	⬭	⬭	⬭	⬭
2. Waste bins are not over flowing, adequate number of waste bins are provided for regular collection and disposal.	⬭	⬭	⬭	⬭	⬭
3. Site is properly fenced off to prevent unauthorized access.	⬭	⬭	⬭	⬭	⬭
4. Old timbers/wooden planks/sheeting/stripped formwork are striked/denailed.	⬭	⬭	⬭	⬭	⬭
5. Isolation tapes and warning notices are provided for plant and equipment temporarily suspended for work execution.	⬭	⬭	⬭	⬭	⬭
6. Supply of potable water and sanitary facilities are adequate and clean.	⬭	⬭	⬭	⬭	⬭
7. Harmful dusts, fumes, vapors or gases are controlled.	⬭	⬭	⬭	⬭	⬭
8. All structures being worked on are stable, safe and not overloaded.	⬭	⬭	⬭	⬭	⬭
9. Noise assessments are conducted and hearing protection zone warnings are placed.	⬭	⬭	⬭	⬭	⬭

15. **Group 8: Personal protective equipment (PPE) (e.g., helmets, eye protection equipment, hearing protection equipment, respiratory protection equipment, gloves, safety footwear, protective outdoor clothing for adverse environments including dusty, wet, or dirty conditions, reflective safety vests or jackets, fall arrest/restrain equipment, shields.)** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Appropriate and adequate personal protective equipment are provided for workers.	⬭	⬭	⬭	⬭	⬭
2. Personal protective equipment is worn by workers properly.	⬭	⬭	⬭	⬭	⬭
3. Adequate instruction and trainings are provided for workers on their use and maintenance.	⬭	⬭	⬭	⬭	⬭
4. Personal protective equipment is in good condition and is properly maintained.	⬭	⬭	⬭	⬭	⬭
5. Wearing of personal protective equipment is encouraged with signage and posters.	⬭	⬭	⬭	⬭	⬭

16. **Group 9: Fire prevention/protection** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Adequate number & proper type of fire extinguishers is available and accessible.	⬭	⬭	⬭	⬭	⬭
2. Fire prevention/protection equipment is regularly checked for serviceability and maintenance provided.	⬭	⬭	⬭	⬭	⬭
3. Fire escape routes kept free of obstructions.	⬭	⬭	⬭	⬭	⬭
4. Site emergency plan and procedures (including steps required to evacuate the site in case of fire), layout plans (showing fire escape routes), assembly points, and emergency telephone numbers are displayed at visible positions.	⬭	⬭	⬭	⬭	⬭
5. Controls of ignition sources/fire watches are provided.	⬭	⬭	⬭	⬭	⬭
6. There are proper storage areas for flammable and combustible wastes, liquids and gases (e.g., LPG and acetylene) with proper signage (e.g., "No Smoking") and these are kept away from direct sunlight.	⬭	⬭	⬭	⬭	⬭
7. A proper alarm system is present (clearly audible at all points on the site).	⬭	⬭	⬭	⬭	⬭

17. **Group 10: Excavation/trenching/shoring/earthworks** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Competent person is assigned for inspection and supervision of the excavation works.	⬭	⬭	⬭	⬭	⬭
2. Underground services are located before excavation and precautionary measures are taken against damages to utilities with the use of detectors, trial pits etc.	⬭	⬭	⬭	⬭	⬭
3. Proper barriers/warning signs/lights are supplied to the excavation.	⬭	⬭	⬭	⬭	⬭
4. Safe access/egress ways are provided for excavation.	⬭	⬭	⬭	⬭	⬭
5. Guard rails or other protection methods are used to prevent people falling into excavation.	⬭	⬭	⬭	⬭	⬭
6. Properly secured stop blocks are provided to prevent tipping vehicles falling into excavation.	⬭	⬭	⬭	⬭	⬭
7. Materials are kept away from the edge of the excavation in order to prevent them from falling into excavation and to reduce the likelihood of a collapse of the side into excavation.	⬭	⬭	⬭	⬭	⬭
8. Adequate/appropriate supporting material is supplied (e.g., sheets, timber, trench boxes, props, etc.) and proper angle of batter (sloping) and shoring is supplied to prevent collapse.	⬭	⬭	⬭	⬭	⬭

18. **Group 11: Concrete formwork/concrete construction** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Grounded electrical vibrators are used.					
2. Workers are protected from cement dust/concrete spread.					
3. Protruding reinforcing rods are covered.					
4. Adequate strength timbers are used.					
5. Side slope bracings/shorings/supports are properly checked.					

19. **Group 12: Gas/electric welding** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Gas/electric welding equipment is daily inspected.					
2. Adequate ventilation is supplied.					
3. Gas cylinders are stored and secured upright and gas lines are in good and protected condition.					
4. Flammable materials protected and proper separating distance is kept between fuels and oxygen.					
5. Fire extinguishers of proper type are held close.					

20. **Group 13: Handling and storage of materials (including hazardous goods and chemicals such as fuels, gas cylinders and other hazardous chemicals, refrigerants, paints, cleansing agents etc.)** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Proper planning is made and adequate number of workers is assigned for handling and storage of materials.	⬭	⬭	⬭	⬭	⬭
2. Storage of dangerous goods and chemicals does not exceed permitted/exempted quantity.	⬭	⬭	⬭	⬭	⬭
3. Materials are securely stored/stacked according to safe loading limits (i.e., not overloading the supporting structure) and tag lines are used to guide loads.	⬭	⬭	⬭	⬭	⬭
4. Hazardous goods and chemicals are removed and disposed by specially trained persons in accordance with statutory requirement.	⬭	⬭	⬭	⬭	⬭
5. Storage for inflammable materials is provided with suitable fencing and shelter, and fuels, paints, varnishes, lacquers and other volatile painting materials are stored in proper containers with adequate warning labels.	⬭	⬭	⬭	⬭	⬭
6. Instruction notices/adequate warning labels/treatment procedures are provided on hazardous goods and chemicals.	⬭	⬭	⬭	⬭	⬭

21. **Group 14: Traffic diversion and transportation control** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Vehicles (Buses/pickups/trucks/other) have regular/proper maintenance and tires, brakes, lights, warning devices are operative.	⬭	⬭	⬭	⬭	⬭
2. Seat belts are used properly.	⬭	⬭	⬭	⬭	⬭
3. Operators/drivers are licensed and trained.	⬭	⬭	⬭	⬭	⬭
4. Weight limits and load sizes are controlled.	⬭	⬭	⬭	⬭	⬭
5. Adequate and proper first aid equipment/fire extinguishers are available in vehicles.	⬭	⬭	⬭	⬭	⬭
6. Traffic motion of vehicles, plants and pedestrians are organized and routes are determined.	⬭	⬭	⬭	⬭	⬭
7. Adequate directional/warning signs are erected for traffic control (e.g., speed limit sign).	⬭	⬭	⬭	⬭	⬭
8. Precautions are taken to avoid tipping of construction vehicles with the use of markers or stoppers.	⬭	⬭	⬭	⬭	⬭
9. Dust suppression measures such as regular watering / covering up the excavated materials are taken during transport.	⬭	⬭	⬭	⬭	⬭

22. **Group 15: First aid facilities** *
Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. First aiders (people trained in first aid) are available on site and their names and contact numbers are announced.					
2. Adequate first aid/medical facilities are present.					
3. First aid boxes are provided at site including isolated locations.					
4. First aid boxes are regularly checked and provisions are replenished.					
5. First aid boxes have first aid instructions on themselves.					
6. Workplace doctor is provided at sites where there are 50 or more workmen.					

23. **Group 16: Demolition works** *
Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
1. Survey is made prior to start of demolition.					
2. Utility service lines are cut off or controlled.					
3. Dust suppression measures are used (e.g., watering).					
4. Protection of people/materials/equipment is provided against collapse/ruins.					
5. Systematic removal of ruins is provided.					

24. **Groups overall** *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Group 1: Working habits of workers	⬭	⬭	⬭	⬭	⬭
Group 2: Scaffoldings and working platforms	⬭	⬭	⬭	⬭	⬭
Group 3: Ladders and stairs	⬭	⬭	⬭	⬭	⬭
Group 4: Hand/power tools, machines, equipment and devices	⬭	⬭	⬭	⬭	⬭
Group 5: Protection against falling	⬭	⬭	⬭	⬭	⬭
Group 6: Lighting and electricity	⬭	⬭	⬭	⬭	⬭
Group 7: Housekeeping, order and tidiness	⬭	⬭	⬭	⬭	⬭
Group 8: Personal protective equipment (PPE) (e.g., helmets, eye protection equipment, hearing protection equipment, respiratory protection equipment, gloves, safety footwear, protective outdoor clothing for adverse environments including dusty, wet, or dirty conditions, reflective safety vests or jackets, fall arrest/restrain equipment, shields.)	⬭	⬭	⬭	⬭	⬭
Group 9: Fire prevention/protection	⬭	⬭	⬭	⬭	⬭
Group 10: Excavation/trenching/shoring/earthworks	⬭	⬭	⬭	⬭	⬭
Group 11: Concrete formwork/concrete construction	⬭	⬭	⬭	⬭	⬭
Group 12: Gas/electric welding	⬭	⬭	⬭	⬭	⬭
Group 13: Handling and storage of materials (including hazardous goods and chemicals such as fuels, gas cylinders and other hazardous chemicals, refrigerants, paints, cleansing agents etc.)	⬭	⬭	⬭	⬭	⬭
Group 14: Traffic diversion and transportation control	⬭	⬭	⬭	⬭	⬭
Group 15: First aid facilities	⬭	⬭	⬭	⬭	⬭
Group 16: Demolition works	⬭	⬭	⬭	⬭	⬭

APPENDIX B

THE FINAL QUESTIONNAIRE FORM

Questionnaire Survey: Groups and variables affecting safety performance of construction sites

Information about Survey

1 / 3		33%

Dear Participant,

Please, press the F11 button on your keyboard for the best view of the questionnarie form.

This questionnarie form has been prepared in the scope of an ongoing PHd thesis study "A Fuzzy Structural Equation Model to Analyze Relationships Between Determinants of Safety Performance in Construction Sites: Development of a Safety Performance Index Assessment Tool" in the Department of Civil Engineering at Middle East Technical University. Filling the questionnaire form will take a part of your valuable time without doubt. However, we strongly wish you help us with filling out the survey to increase consciousness in safety.

Collected information will absolutely be kept confidential. Thanks for your kind support and we wish you good luck. Sincerely yours,

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BOTAŞ, Project Controls Manager
METU, Civil Engineering Dept. Doctorate Student
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Next

Questionnaire Survey: Groups and variables affecting safety performance of construction sites

Part-1: General Information

2 / 3 67%

Dear Participant;

This part consists of questions regarding you and the company you are working for. Please select the suitable choices / fill in the blanks.

Which sector are you working for?

Public

Private

Other (please specify)

Which party are you working for?

Owner

Contractor

Consultant

Other (please specify)

What is your position at your company?

Owner

Manager

Engineer-Supervisor

Technician-Foreman

Other (please specify)

* Do you own occupational safety expertise certificate?

No

Yes, Class A

Yes, Class B

Yes, Class C

Areas of expertise of company you work for?

Building Construction

Transport

Infrastructure

Hydraulic Structures

Industrial Facilities

Other (please specify)

* How many years have you been working for this company?

* How many years have you been working in construction industry?

Prev Next

Part-2: Groups and Variables affecting Safety Performance of Construction Sites

3 / 3 100%

Dear Participant;

16 groups and 168 variables affecting "Safety Performance of Construction Sites' are listed below.

Please, select the suitable expression checkbox next to groups and variables by taking into account their "PROBABILITY of an INCIDENT" and "IMPACT of an INCIDENT".

* GROUP 1) SCAFFOLDINGS AND WORKING PLATFORMS

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
1.1 Lack of installation, operation and disassembly plan for the scaffolding	▼	▼
1.2 Use of defective and worn fasteners in scaffolding system	▼	▼
1.3 Improper fastening and supporting against horizontal and vertical forces	▼	▼
1.4 Leaving rubbish and waste material on scaffoldings and platforms blocking people to pass	▼	▼
1.5 Use of non-standard guard rails, intermediate rails, toe boards, screens and plankings	▼	▼
1.6 Absence of gateways having proper system at scaffoldings	▼	▼
1.7 Failure to take preventive measures (barrier/warning notices) for incomplete/unsafe scaffolds	▼	▼
1.8 Failure to control before use	▼	▼
1.9 Failure to hang sign boards indicating the maximum load capacity that scaffoldings can bear at proper and visible places	▼	▼
1.10 Overloading the scaffoldings and platforms	▼	▼
1.11 Assembly and disassembly by inexperienced people	▼	▼
1.12 Failure to use proper personal protective equipment (PPE)	▼	▼

* GROUP 2) LADDERS AND STAIRS

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
2.1 To be made of weak and defective material	▼	▼
2.2 Use of equipment with damaged rungs, arms or connection parts	▼	▼
2.3 Failure to base on firm and leveled foundation	▼	▼
2.4 Failure to fix bottom and top parts properly	▼	▼
2.5 Failure to tag ladders with missing parts	▼	▼
2.6 Being improper for the job	▼	▼
2.7 Failure to position at the correct angle	▼	▼
2.8 Failure to clean enough	▼	▼
2.9 Failure to position safe distances (Vehicles, mobile cranes and electricity lines etc.)	▼	▼
2.10 Lack of daily inspection and maintenance	▼	▼

* GROUP 3) WORKING AT HEIGHT AND PROTECTION AGAINST FALLING

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
3.1 Failure to plan the work to be done in advance and failure to make the required organizations	▼	▼
3.2 Failure to place barrier and warning signs for open edges and holes	▼	▼
3.3 Safety nets and air bags not complying with standards	▼	▼
3.4 Guardrails, handrails or rails not complying with standards	▼	▼
3.5 Employee's access to working places by inconvenient means and equipment	▼	▼
3.6 Failure to take preventive measures against falling of hand tools and other materials	▼	▼
3.7 Failure to prevent access to the areas subject to falling objects or failure to erect covered gateways	▼	▼
3.8 Lack of regular inspection and maintenance of safe working equipment used at heights	▼	▼
3.9 Failure to use proper personal protective equipment (PPE)	▼	▼

✱ GROUP 4) LIGHTING AND ELECTRICITY

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
4.1 Failure to supply adequate illumination for working places, passageways and routes		
4.2 Lack of auxiliary illumination system against electricity cuts		
4.3 Use of improper connectors (E.g.: connections with open-ended cables)		
4.4 Lack of utilization of proper residual current device in the main and secondary electricity panels		
4.5 Failure to put the panels, boards, control apparatus, etc. into lockers or cabinets		
4.6 Failure to enclose cabinets, panels and switches in weather-proof enclosures located in wet locations		
4.7 Failure to mark overhead lines and failure to take appropriate measures to prevent contact		
4.8 All of the hardware and connection work done by unauthorized people		
4.9 Failure to place electrical danger posts and warning signs		
4.10 Failure to use proper personal protective equipment (PPE)		

✱ GROUP 5) HOUSEKEEPING, ORDER AND TIDINESS

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
5.1 Lack of sufficient space for working areas		
5.2 Failure to provide appropriate places where employees can relax		
5.3 Dumping the garbage negligently and failure to collect the garbage regularly		
5.4 Failure to take preventive measures (barriers/warning signs) for slippery surfaces		
5.5 Lack of fencing the construction site properly to prevent unauthorized entry		
5.6 Leaving waste and materials with sharp and keen edges (E.g.: form with nails) in the working areas		
5.7 Failure to provide isolation tapes and warning notices for plant and equipment temporarily suspended for work execution		
5.8 The sanitary facilities are inadequate and failure to maintain the hygiene requirements		

5.9 Failure to provide sufficient amount of potable water		
5.10 Failure to perform chemical and biological analyzes for potable water		
5.11 Failure to perform measurement and control of harmful dusts, gases, fumes, vapors, vibration, noise, pollution		
5.12 Failure to take necessary measures for protection of workers from too hot and cold		

*GROUP 6) PERSONAL PROTECTIVE EQUIPMENT (PPE)

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
6.1 Lack of having appropriate standards		
6.2 Failure to access easily		
6.3 Failure to provide adequate amounts		
6.4 Lack of correct and proper use by workers		
6.5 Lack of inspection before each use		
6.6 Use of equipment although it is damaged		
6.7 Failure to provide adequate instruction and practical training for use and maintenance		
6.8 Failure to regularly maintain and clean		
6.9 Failure to encourage its use by means of signboard and posters		

*GROUP 7) FIRE PREVENTION/PROTECTION

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
7.1 Lack of adequate number and proper type of fire extinguishers		
7.2 Fire extinguishers are not easily accessible or obstacles are present in front of them		
7.3 Lack of proper and permanent marking for emergency escape routes and exits		
7.4 Lack of uninterrupted and adequate lighting system for emergency escape routes and exits		
7.5 Existing obstacles in front of emergency escape routes and exits making difficult to quit		
7.6 Failure to display emergency plan, procedures, assembly points and emergency telephone numbers at visible positions		

7.7 Lack of adequate/proper number and quality of fire detectors	▼	▼
7.8 Lack of proper alarm system clearly audible at all points on the site	▼	▼
7.9 Lack of regular inspection and maintenance of firefighting equipment, detectors and alarm systems	▼	▼
7.10 Failure to conduct fire drill at regular intervals	▼	▼

*GROUP 8) HAND/POWER TOOLS, MACHINERY AND DEVICES

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
8.1 Improper use and use for purposes other than it is intended	▼	▼
8.2 Use or operate of tools, machines and devices without security protection inserted	▼	▼
8.3 Use without making sure of the soundness of the floor and use without fixing	▼	▼
8.4 Use or operate in damaged condition	▼	▼
8.5 Use or operate by untrained and unauthorized operators	▼	▼
8.6 Lack of absence of a trained pointer to guide operator in necessary situations	▼	▼
8.7 Lack of daily inspection and maintenance	▼	▼
8.8 Lack of safe work instructions	▼	▼
8.9 Failure to clean enough	▼	▼
8.10 Failure to place barricades and warning signs when not in use	▼	▼
8.11 Failure to position in safe distances (E.g.: people, materials, tools, excavation, slope, underground facility, soft ground, obstacles, electricity lines)	▼	▼
8.12 Failure to use proper personal protective equipment (PPE)	▼	▼

*GROUP 9) MATERIAL HANDLING (LOADING, TRANSPORT, UNLOADING, HANDLING AND STORAGE)

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
9.1 Lack of proper planning	▼	▼
9.2 Transportation by improper vehicles	▼	▼
9.3 Failure to comply with safe loading limitations	▼	▼

9.4 Loading/unloading/stacking by unsafe vehicles	▼	▼
9.5 Failure to design loading places and ramps according to dimensions of the load to be moved	▼	▼
9.6 Lack of use of forwarding lines that guide loads	▼	▼
9.7 Failure to remove/disposal of hazardous materials and chemicals by specially trained personnel	▼	▼
9.8 Storage of hazardous materials and chemicals more than the allowed/exempted amount	▼	▼
9.9 Absence of legible warning labels on hazardous materials and chemicals	▼	▼
9.10 Absence of Material safety data sheet (MSDS) belonging to hazardous materials and chemicals	▼	▼
9.11 Failure to clearly display chemical hazard communication plan	▼	▼
9.12 Failure to use proper personal protective equipment (PPE)	▼	▼

* GROUP 10) TRAFFIC AND TRANSPORTATION CONTROL

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
10.1 Lack of correct and regular inspection and maintenance of vehicles	▼	▼
10.2 Failure to use safety belts	▼	▼
10.3 Driving vehicle without license	▼	▼
10.4 Driving vehicle without experience	▼	▼
10.5 Absence of proper and adequate first aid kit/fire extinguisher tube in vehicles	▼	▼
10.6 Unclear routes	▼	▼
10.7 Roads with inadequate width	▼	▼
10.8 Failure to keep adequate distance between roads (having vehicle traffic) and doors, gates, pedestrian passageways, corridors and stairs	▼	▼
10.9 Lack of adequate number of direction and warning signs	▼	▼
10.10 Failure to comply with speed limits	▼	▼
10.11 Failure to take preventive measures against excavation material spillage and dust	▼	▼
10.12 Failure to take preventive measures against the entry of unauthorized people to prohibited areas	▼	▼

*GROUP 11) FIRST AID

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
11.1 Absence of trained first aid staff at site		
11.2 Failure to display first aid staff and their contact information at visible positions		
11.3 Lack of adequate number of first aid supplies and equipment		
11.4 Lack of adequate number of first aid supplies and equipment		
11.5 First aid supplies and equipment are not ready for use		
11.6 First aid supplies and equipment are not marked appropriately		
11.7 Lack of adequate number of emergency treatment rooms		
11.8 Absence of on-site doctor		

*GROUP 12) EXCAVATION WORKS

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
12.1 Inspection and control of excavation works by unauthorized people		
12.2 Failure to locate beforehand underground facilities in excavation areas by using detectors, etc. (E.g.: cable, gas, water, sewer lines)		
12.3 Failure to place proper barriers, railings and warning signs		
12.4 Performing night work without providing adequate lighting		
12.5 Use of unsafe entry and exit gates to access working area		
12.6 Failure to place secured stop blocks preventing the vehicles from falling into excavation area		
12.7 Placing the materials improperly near to the excavation edges		
12.8 Failure to support properly and adequately by performing static calculations of the excavation area (with slab, timber, trench boxes, shoring, lining, etc.)		
12.9 Sloping the excavation area with improper angles		
12.10 Performing excavation works while raining		

12.11 Entry of unauthorized people to the excavation area	▼	▼
12.12 Failure to use proper personal protective equipment (PPE)	▼	▼

∗GROUP 13) CONCRETE AND FORMWORK

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
13.1 Failure to perform form works under the supervision of a competent person	▼	▼
13.2 Improper design and installation of form panels, supports and struts with respect to the loads on it	▼	▼
13.3 Use of weak and deformed forms	▼	▼
13.4 Use of ungrounded electrical vibrator	▼	▼
13.5 Exposure of reinforcing bars	▼	▼
13.6 Failure to position the concrete pump properly to the ground that concrete will be poured	▼	▼
13.7 Failure to fix the concrete pump's supporting foots to the ground	▼	▼
13.8 Failure to take account of surrounding facilities while opening and closing pump handles	▼	▼
13.9 Operating the pump under energy transmission lines without taking precautions	▼	▼
13.10 Performing work directly below the concrete pouring area	▼	▼
13.11 Failure to use proper personal protective equipment (PPE)	▼	▼

∗GROUP 14) WELDING WORKS

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
14.1 Lack of daily control and maintenance of the welding equipment	▼	▼
14.2 Inadequate ventilation in narrow and confined areas	▼	▼
14.3 Failure to keep gas cylinders upright and failure to fasten in order not to overturn when shaked	▼	▼
14.4 Absence of proper type of fire extinguisher nearby	▼	▼
14.5 Failure to put adequate separation distance between fuels and oxygen	▼	▼
14.6 Contact oxygen tube with oily hand	▼	▼

14.7 Failure to take precautions against electrical and gas leakage	▼	▼
14.8 Use of deformed hoses	▼	▼
14.9 Welders without license and certificate	▼	▼
14.10 Failure to use proper personal protective equipment (PPE)	▼	▼

*GROUP 15) DEMOLITION WORKS

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
15.1 Lack of preparation and planning of actions before the start of demolition works	▼	▼
15.2 Failure to enclose the demolition area and failure to place warning signs	▼	▼
15.3 Failure to take existing service lines (gas, water, electricity lines, etc.) under control or failure to cut whereas necessary	▼	▼
15.4 Performing demolition works under the supervision of an incompetent person	▼	▼
15.5 Failure to remove people, vehicles, materials and equipment enough from the demolition area	▼	▼
15.6 Failure to take necessary precautions to avoid dust during demolition	▼	▼
15.7 Failure to transport materials and ruins in a systematical and secured way	▼	▼
15.8 Failure to perform asbestos powder measurement for structures that may contain asbestos	▼	▼
15.9 Failure to use proper personal protective equipment (PPE)	▼	▼

*GROUP 16) WORKERS

	"PROBABILITY of an INCIDENT"	"IMPACT of an INCIDENT"
16.1 Avoiding the use of personal protective equipment intentionally	▼	▼
16.2 Taking the apparent risks	▼	▼
16.3 Performing erroneous methods and applications	▼	▼
16.4 Working without plan and cautiousness	▼	▼
16.5 Lacking safety consciousness	▼	▼
16.6 Working without morale	▼	▼

16.7 Working without permission	▼	▼
16.8 Use of alcohol and drug	▼	▼
16.9 The continuous change of workers (Personnel turnover rate is high)	▼	▼
16.10 Inadequacy of safety trainings	▼	▼

Prev Done

APPENDIX C

VARIABLES AFFECTING SAFETY PERFORMANCE (WITH CORRESPONDING ABBREVIATIONS)

Table C.1: Variables affecting safety performance with corresponding abbreviations

OBSERVED VARIABLES AND LATENT DIMENSIONS AFFECTING SAFETY PERFORMANCE	ABBREVIATIONS
SAFETY PERFORMANCE	**SP**
1) SCAFFOLDINGS AND WORKING PLATFORMS	**G1**
1.1 Lack of installation, operation and disassembly plan for the scaffolding	G1F1
1.2 Use of defective and worn fasteners in scaffolding system	G1F2
1.3 Improper fastening and supporting against horizontal and vertical forces	G1F3
1.4 Leaving rubbish and waste material on scaffoldings and platforms blocking people to pass	G1F4
1.5 Use of non-standard guard rails, intermediate rails, toe boards, screens and plankings	G1F5
1.6 Absence of gateways having proper system at scaffoldings	G1F6
1.7 Failure to take preventive measures (barrier/warning notices) for incomplete/unsafe scaffolds	G1F7
1.8 Failure to control before use	G1F8
1.9 Failure to hang sign boards indicating the maximum load capacity that scaffoldings can bear at proper and visible places	G1F9
1.10 Overloading the scaffoldings and platforms	G1F10
1.11 Assembly and disassembly by inexperienced people	G1F11
1.12 Failure to use proper personal protective equipment (PPE)	G1F12

Table C.1: Variables affecting safety performance with corresponding abbreviations (Cont'd)

OBSERVED VARIABLES AND LATENT DIMENSIONS AFFECTING SAFETY PERFORMANCE	ABBREVIATIONS
2) LADDERS AND STAIRS	**G2**
2.1 To be made of weak and defective material	G2F1
2.2 Use of equipment with damaged rungs, arms or connection parts	G2F2
2.3 Failure to base on firm and leveled foundation	G2F3
2.4 Failure to fix bottom and top parts properly	G2F4
2.5 Failure to tag ladders with missing parts	G2F5
2.6 Being improper for the job	G2F6
2.7 Failure to position at the correct angle	G2F7
2.8 Failure to clean enough	G2F8
2.9 Failure to position safe distances (Vehicles, mobile cranes and electricity lines etc.)	G2F9
2.10 Lack of daily inspection and maintenance	G2F10
3) WORKING AT HEIGHT AND PROTECTION AGAINST FALLING	**G3**
3.1 Failure to plan the work to be done in advance and failure to make the required organizations	G3F1
3.2 Failure to place barrier and warning signs for open edges and holes	G3F2
3.3 Safety nets and air bags not complying with standards	G3F3
3.4 Guardrails, handrails or rails not complying with standards	G3F4
3.5 Employee's access to working places by inconvenient means and equipment	G3F5
3.6 Failure to take preventive measures against falling of hand tools and other materials	G3F6
3.7 Failure to prevent access to the areas subject to falling objects or failure to erect covered gateways	G3F7
3.8 Lack of regular inspection and maintenance of safe working equipment used at heights	G3F8
3.9 Failure to use proper personal protective equipment (PPE)	G3F9

Table C.1: Variables affecting safety performance with corresponding abbreviations (Cont'd)

OBSERVED VARIABLES AND LATENT DIMENSIONS AFFECTING SAFETY PERFORMANCE	ABBREVIATIONS
4) LIGHTING AND ELECTRICITY	**G4**
4.1 Failure to supply adequate illumination for working places, passageways and routes	G4F1
4.2 Lack of auxiliary illumination system against electricity cuts	G4F2
4.3 Use of improper connectors (E.g.: connections with open-ended cables)	G4F3
4.4 Lack of utilization of proper residual current device in the main and secondary electricity panels	G4F4
4.5 Failure to put the panels, boards, control apparatus, etc. into lockers or cabinets	G4F5
4.6 Failure to enclose cabinets, panels and switches in weather-proof enclosures located in wet locations	G4F6
4.7 Failure to mark overhead lines and failure to take appropriate measures to prevent contact	G4F7
4.8 All of the hardware and connection work done by unauthorized people	G4F8
4.9 Failure to place electrical danger posts and warning signs	G4F9
4.10 Failure to use proper personal protective equipment (PPE)	G4F10
5) HOUSEKEEPING, ORDER AND TIDINESS	**G5**
5.1 Lack of sufficient space for working areas	G5F1
5.2 Failure to provide appropriate places where employees can relax	G5F2
5.3 Dumping the garbage negligently and failure to collect the garbage regularly	G5F3
5.4 Failure to take preventive measures (barriers/warning signs) for slippery surfaces	G5F4
5.5 Lack of fencing the construction site properly to prevent unauthorized entry	G5F5
5.6 Leaving waste and materials with sharp and keen edges (E.g.: form with nails) in the working areas	G5F6
5.7 Failure to provide isolation tapes and warning notices for plant and equipment temporarily suspended for work execution	G5F7
5.8 The sanitary facilities are inadequate and failure to maintain the hygiene requirements	G5F8

Table C.1: Variables affecting safety performance with corresponding abbreviations (Cont'd)

OBSERVED VARIABLES AND LATENT DIMENSIONS AFFECTING SAFETY PERFORMANCE	ABBREVIATIONS
5.9 Failure to provide sufficient amount of potable water	G5F9
5.10 Failure to perform chemical and biological analyzes for potable water	G5F10
5.11 Failure to perform measurement and control of harmful dusts, gases, fumes, vapors, vibration, noise, pollution	G5F11
5.12 Failure to take necessary measures for protection of workers from too hot and cold	G5F12
6) PERSONAL PROTECTIVE EQUIPMENT (PPE)	**G6**
6.1 Lack of having appropriate standards	G6F1
6.2 Failure to access easily	G6F2
6.3 Failure to provide adequate amounts	G6F3
6.4 Lack of correct and proper use by workers	G6F4
6.5 Lack of inspection before each use	G6F5
6.6 Use of equipment although it is damaged	G6F6
6.7 Failure to provide adequate instruction and practical training for use and maintenance	G6F7
6.8 Failure to regularly maintain and clean	G6F8
6.9 Failure to encourage its use by means of signboard and posters	G6F9
7) FIRE PREVENTION/PROTECTION	**G7**
7.1 Lack of adequate number and proper type of fire extinguishers	G7F1
7.2 Fire extinguishers are not easily accessible or obstacles are present in front of them	G7F2
7.3 Lack of proper and permanent marking for emergency escape routes and exits	G7F3
7.4 Lack of uninterrupted and adequate lighting system for emergency escape routes and exits	G7F4
7.5 Existing obstacles in front of emergency escape routes and exits making difficult to quit	G7F5
7.6 Failure to display emergency plan, procedures, assembly points and emergency telephone numbers at visible positions	G7F6

Table C.1: Variables affecting safety performance with corresponding abbreviations (Cont'd)

7.7 Lack of adequate/proper number and quality of fire detectors	G7F7
7.8 Lack of proper alarm system clearly audible at all points on the site	G7F8
7.9 Lack of regular inspection and maintenance of firefighting equipment, detectors and alarm systems	G7F9
7.10 Failure to conduct fire drill at regular intervals	G7F10
8) HAND/POWER TOOLS, MACHINERY AND DEVICES	**G8**
8.1 Improper use and use for purposes other than it is intended	G8F1
8.2 Use or operate of tools, machines and devices without security protection inserted	G8F2
8.3 Use without making sure of the soundness of the floor and use without fixing	G8F3
8.4 Use or operate in damaged condition	G8F4
8.5 Use or operate by untrained and unauthorized operators	G8F5
8.6 Lack of absence of a trained pointer to guide operator in necessary situations	G8F6
8.7 Lack of daily inspection and maintenance	G8F7
8.8 Lack of safe work instructions	G8F8
8.9 Failure to clean enough	G8F9
8.10 Failure to place barricades and warning signs when not in use	G8F10
8.11 Failure to position in safe distances (E.g.: people, materials, tools, excavation, slope, underground facility, soft ground, obstacles, electricity lines)	G8F11
8.12 Failure to use proper personal protective equipment (PPE)	G8F12

Table C.1: Variables affecting safety performance with corresponding abbreviations (Cont'd)

OBSERVED VARIABLES AND LATENT DIMENSIONS AFFECTING SAFETY PERFORMANCE	ABBREVIATIONS
7.7 Lack of adequate/proper number and quality of fire detectors	G7F7
7.8 Lack of proper alarm system clearly audible at all points on the site	G7F8
7.9 Lack of regular inspection and maintenance of firefighting equipment, detectors and alarm systems	G7F9
7.10 Failure to conduct fire drill at regular intervals	G7F10
8) HAND/POWER TOOLS, MACHINERY AND DEVICES	**G8**
8.1 Improper use and use for purposes other than it is intended	G8F1
8.2 Use or operate of tools, machines and devices without security protection inserted	G8F2
8.3 Use without making sure of the soundness of the floor and use without fixing	G8F3
8.4 Use or operate in damaged condition	G8F4
8.5 Use or operate by untrained and unauthorized operators	G8F5
8.6 Lack of absence of a trained pointer to guide operator in necessary situations	G8F6
8.7 Lack of daily inspection and maintenance	G8F7
8.8 Lack of safe work instructions	G8F8
8.9 Failure to clean enough	G8F9
8.10 Failure to place barricades and warning signs when not in use	G8F10
8.11 Failure to position in safe distances (E.g.: people, materials, tools, excavation, slope, underground facility, soft ground, obstacles, electricity lines)	G8F11
8.12 Failure to use proper personal protective equipment (PPE)	G8F12
9) MATERIAL HANDLING (LOADING, TRANSPORT, UNLOADING, HANDLING AND STORAGE)	**G9**
9.1 Lack of proper planning	G9F1
9.2 Transportation by improper vehicles	G9F2
9.3 Failure to comply with safe loading limitations	G9F3

Table C.1: Variables affecting safety performance with corresponding abbreviations (Cont'd)

OBSERVED VARIABLES AND LATENT DIMENSIONS AFFECTING SAFETY PERFORMANCE	ABBREVIATIONS
9.4 Loading/unloading/stacking by unsafe vehicles	G9F4
9.5 Failure to design loading places and ramps according to dimensions of the load to be moved	G9F5
9.6 Lack of use of forwarding lines that guide loads	G9F6
9.7 Failure to remove/disposal of hazardous materials and chemicals by specially trained personnel	G9F7
9.8 Storage of hazardous materials and chemicals more than the allowed/exempted amount	G9F8
9.9 Absence of legible warning labels on hazardous materials and chemicals	G9F9
9.10 Absence of Material safety data sheet (MSDS) belonging to hazardous materials and chemicals	G9F10
9.11 Failure to clearly display chemical hazard communication plan	G9F11
9.12 Failure to use proper personal protective equipment (PPE)	G9F12
10) TRAFFIC AND TRANSPORTATION CONTROL	**G10**
10.1 Lack of correct and regular inspection and maintenance of vehicles	G10F1
10.2 Failure to use safety belts	G10F2
10.3 Driving vehicle without license	G10F3
10.4 Driving vehicle without experience	G10F4
10.5 Absence of proper and adequate first aid kit/fire extinguisher tube in vehicles	G10F5
10.6 Unclear routes	G10F6
10.7 Roads with inadequate width	G10F7
10.8 Failure to keep adequate distance between roads (having vehicle traffic) and doors, gates, pedestrian passageways, corridors and stairs	G10F8
10.9 Lack of adequate number of direction and warning signs	G10F9
10.10 Failure to comply with speed limits	G10F10
10.11 Failure to take preventive measures against excavation material spillage and dust	G10F11

Table C.1: Variables affecting safety performance with corresponding abbreviations (Cont'd)

OBSERVED VARIABLES AND LATENT DIMENSIONS AFFECTING SAFETY PERFORMANCE	ABBREVIATIONS
10.12 Failure to take preventive measures against the entry of unauthorized people to prohibited areas	G10F12
11) FIRST AID	**G11**
11.1 Absence of trained first aid staff at site	G11F1
11.2 Failure to display first aid staff and their contact information at visible positions	G11F2
11.3 Lack of adequate number of first aid supplies and equipment	G11F3
11.4 Lack of easy to access first aid supplies and equipment	G11F4
11.5 First aid supplies and equipment are not ready for use	G11F5
11.6 First aid supplies and equipment are not marked appropriately	G11F6
11.7 Lack of adequate number of emergency treatment rooms	G11F7
11.8 Absence of on-site doctor	G11F8
12) EXCAVATION WORKS	**G12**
12.1 Inspection and control of excavation works by unauthorized people	G12F1
12.2 Failure to locate beforehand underground facilities in excavation areas by using detectors, etc. (E.g.: cable, gas, water, sewer lines)	G12F2
12.3 Failure to place proper barriers, railings and warning signs	G12F3
12.4 Performing night work without providing adequate lighting	G12F4
12.5 Use of unsafe entry and exit gates to access working area	G12F5
12.6 Failure to place secured stop blocks preventing the vehicles from falling into excavation area	G12F6
12.7 Placing the materials improperly near to the excavation edges	G12F7
12.8 Failure to support properly and adequately by performing static calculations of the excavation area (with slab, timber, trench boxes, shoring, lining, etc.)	G12F8
12.9 Sloping the excavation area with improper angles	G12F9

Table C.1: Variables affecting safety performance with corresponding abbreviations (Cont'd)

OBSERVED VARIABLES AND LATENT DIMENSIONS AFFECTING SAFETY PERFORMANCE	ABBREVIATIONS
12.10 Performing excavation works while raining	G12F10
12.11 Entry of unauthorized people to the excavation area	G12F11
12.12 Failure to use proper personal protective equipment (PPE)	G12F12
13) CONCRETE AND FORMWORK	**G13**
13.1 Failure to perform form works under the supervision of a competent person	G13F1
13.2 Improper design and installation of form panels, supports and struts with respect to the loads on it	G13F2
13.3 Use of weak and deformed forms	G13F3
13.4 Use of ungrounded electrical vibrator	G13F4
13.5 Exposure of reinforcing bars	G13F5
13.6 Failure to position the concrete pump properly to the ground that concrete will be poured	G13F6
13.7 Failure to fix the concrete pump's supporting foots to the ground	G13F7
13.8 Failure to take account of surrounding facilities while opening and closing pump handles	G13F8
13.9 Operating the pump under energy transmission lines without taking precautions	G13F9
13.10 Performing work directly below the concrete pouring area	G13F10
13.11 Failure to use proper personal protective equipment (PPE)	G13F11
14) WELDING WORKS	**G14**
14.1 Lack of daily control and maintenance of the welding equipment	G14F1
14.2 Inadequate ventilation in narrow and confined areas	G14F2
14.3 Failure to keep gas cylinders upright and failure to fasten in order not to overturn when shaked	G14F3
14.4 Absence of proper type of fire extinguisher nearby	G14F4
14.5 Failure to put adequate separation distance between fuels and oxygen	G14F5

Table C.1: Variables affecting safety performance with corresponding abbreviations (Cont'd)

OBSERVED VARIABLES AND LATENT DIMENSIONS AFFECTING SAFETY PERFORMANCE	ABBREVIATIONS
14.6 Contact oxygen tube with oily hand	G14F6
14.7 Failure to take precautions against electrical and gas leakage	G14F7
14.8 Use of deformed hoses	G14F8
14.9 Welders without license and certificate	G14F9
14.10 Failure to use proper personal protective equipment (PPE)	G14F10
15) DEMOLITION WORKS	**G15**
15.1 Lack of preparation and planning of actions before the start of demolition works	G15F1
15.2 Failure to enclose the demolition area and failure to place warning signs	G15F2
15.3 Failure to take existing service lines (gas, water, electricity lines, etc.) under control or failure to cut whereas necessary	G15F3
15.4 Performing demolition works under the supervision of an incompetent person	G15F4
15.5 Failure to remove people, vehicles, materials and equipment enough from the demolition area	G15F5
15.6 Failure to take necessary precautions to avoid dust during demolition	G15F6
15.7 Failure to transport materials and ruins in a systematical and secured way	G15F7
15.8 Failure to perform asbestos powder measurement for structures that may contain asbestos	G15F8
15.9 Failure to use proper personal protective equipment (PPE)	G15F9
16) WORKERS	**G16**
16.1 Avoiding the use of personal protective equipment intentionally	G16F1
16.2 Taking the apparent risks	G16F2
16.3 Performing erroneous methods and applications	G16F3
16.4 Working without plan and cautiousness	G16F4
16.5 Lacking safety consciousness	G16F5

Table C.1: Variables affecting safety performance with corresponding abbreviations (Cont'd)

OBSERVED VARIABLES AND LATENT DIMENSIONS AFFECTING SAFETY PERFORMANCE	ABBREVIATIONS
16.6 Working without morale	G16F6
16.7 Working without permission	G16F7
16.8 Use of alcohol and drug	G16F8
16.9 The continuous change of workers (Personnel turnover rate is high)	G16F9
16.10 Inadequacy of safety trainings	G16F10

APPENDIX D

DESCRIPTIVE STATISTICS

Table D.1: Descriptive statistics

	N	Range	Min	Max	Sum	Mean	Std. Dev.	Vari- ance	Skewness		Kurtosis	
	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Std. Err.	Stat.	Std. Err.
G1F1	180	,850	,075	,925	139,350	,77417	,216722	,047	-1,566	,181	2,011	,360
G1F2	180	,850	,075	,925	151,925	,84403	,172424	,030	-2,577	,181	6,944	,360
G1F3	180	,850	,075	,925	152,750	,84861	,165235	,027	-2,563	,181	7,184	,360
G1F4	180	,850	,075	,925	119,225	,66236	,236234	,056	-,479	,181	-,565	,360
G1F5	180	,850	,075	,925	134,025	,74458	,228094	,052	-1,236	,181	,944	,360
G1F6	180	,850	,075	,925	125,850	,69917	,243260	,059	-,834	,181	-,112	,360
G1F7	180	,850	,075	,925	124,500	,69167	,263265	,069	-,880	,181	-,284	,360
G1F8	180	,850	,075	,925	131,775	,73208	,234242	,055	-1,025	,181	,233	,360
G1F9	180	,850	,075	,925	106,625	,59236	,270798	,073	-,396	,181	-,722	,360
G1F10	180	,850	,075	,925	149,175	,82875	,187893	,035	-2,275	,181	5,120	,360
G1F11	180	,850	,075	,925	148,250	,82361	,170620	,029	-1,923	,181	3,923	,360
G1F12	180	,850	,075	,925	133,775	,74319	,223526	,050	-1,114	,181	,561	,360
G2F1	180	,850	,075	,925	132,400	,73556	,233775	,055	-1,047	,181	,189	,360
G2F2	180	,850	,075	,925	129,925	,72181	,234611	,055	-,982	,181	,161	,360
G2F3	180	,850	,075	,925	139,000	,77222	,222823	,050	-1,444	,181	1,334	,360
G2F4	180	,850	,075	,925	137,125	,76181	,219134	,048	-1,260	,181	,845	,360
G2F5	180	,850	,075	,925	113,175	,62875	,277099	,077	-,408	,181	-,993	,360
G2F6	180	,850	,075	,925	124,950	,69417	,244993	,060	-,766	,181	-,251	,360
G2F7	180	,850	,075	,925	114,825	,63792	,262674	,069	-,470	,181	-,725	,360
G2F8	180	,850	,075	,925	77,725	,43181	,272043	,074	,261	,181	-,890	,360
G2F9	180	,850	,075	,925	127,200	,70667	,248524	,062	-,828	,181	-,313	,360
G2F10	180	,850	,075	,925	103,675	,57597	,261607	,068	-,182	,181	-,827	,360

Table D.1: Descriptive statistics (Cont'd)

	N	Range	Min	Max	Sum	Mean	Std. Dev.	Vari-ance	Skewness		Kurtosis	
	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Std. Err.	Stat.	Std. Err.
G3F1	180	,850	,075	,925	131,800	,73222	,218497	,048	-,815	,181	-,202	,360
G3F2	180	,850	,075	,925	144,450	,80250	,175669	,031	-1,325	,181	1,168	,360
G3F3	180	,850	,075	,925	131,300	,72944	,213071	,045	-,863	,181	,185	,360
G3F4	180	,850	,075	,925	135,550	,75306	,202803	,041	-,981	,181	,258	,360
G3F5	180	,850	,075	,925	128,275	,71264	,248578	,062	-,893	,181	-,283	,360
G3F6	180	,850	,075	,925	132,000	,73333	,229768	,053	-,994	,181	,071	,360
G3F7	180	,850	,075	,925	133,550	,74194	,231865	,054	-1,193	,181	,741	,360
G3F8	180	,850	,075	,925	130,125	,72292	,225099	,051	-,851	,181	-,092	,360
G3F9	180	,850	,075	,925	134,350	,74639	,228352	,052	-1,153	,181	,521	,360
G4F1	180	,850	,075	,925	123,200	,68444	,242487	,059	-,622	,181	-,544	,360
G4F2	180	,850	,075	,925	112,875	,62708	,280909	,079	-,496	,181	-,905	,360
G4F3	180	,850	,075	,925	146,875	,81597	,191013	,036	-1,958	,181	3,552	,360
G4F4	180	,850	,075	,925	140,475	,78042	,213776	,046	-1,442	,181	1,400	,360
G4F5	180	,850	,075	,925	122,325	,67958	,267730	,072	-,787	,181	-,458	,360
G4F6	180	,850	,075	,925	130,350	,72417	,262134	,069	-1,082	,181	-,021	,360
G4F7	180	,850	,075	,925	137,600	,76444	,210910	,044	-1,230	,181	,962	,360
G4F8	180	,850	,075	,925	139,850	,77694	,214269	,046	-1,399	,181	1,280	,360
G4F9	180	,850	,075	,925	116,100	,64500	,248886	,062	-,573	,181	-,550	,360
G4F10	180	,850	,075	,925	134,175	,74542	,225589	,051	-1,144	,181	,573	,360
G5F1	180	,850	,075	,925	87,725	,48736	,261128	,068	-,030	,181	-,726	,360
G5F2	180	,850	,075	,925	77,275	,42931	,267800	,072	,273	,181	-,725	,360
G5F3	180	,850	,075	,925	77,975	,43319	,285690	,082	,267	,181	-,975	,360
G5F4	180	,850	,075	,925	120,975	,67208	,242056	,059	-,643	,181	-,350	,360
G5F5	180	,850	,075	,925	119,100	,66167	,269484	,073	-,657	,181	-,663	,360
G5F6	180	,850	,075	,925	120,975	,67208	,242719	,059	-,649	,181	-,280	,360
G5F7	180	,850	,075	,925	112,525	,62514	,269187	,072	-,478	,181	-,792	,360
G5F8	180	,850	,075	,925	90,175	,50097	,293164	,086	,017	,181	-1,120	,360
G5F9	180	,850	,075	,925	76,725	,42625	,300271	,090	,309	,181	-1,118	,360
G5F10	180	,850	,075	,925	91,000	,50556	,274416	,075	,028	,181	-,997	,360
G5F11	180	,850	,075	,925	106,675	,59264	,270406	,073	-,286	,181	-,892	,360

Table D.1: Descriptive statistics (Cont'd)

	N	Range	Min	Max	Sum	Mean	Std. Dev.	Vari-ance	Skewness		Kurtosis	
	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Std. Err.	Stat.	Std. Err.
G5F12	180	,850	,075	,925	94,500	,52500	,289384	,084	-,094	,181	-1,061	,360
G6F1	180	,850	,075	,925	115,450	,64139	,280566	,079	-,580	,181	-,758	,360
G6F2	180	,850	,075	,925	100,425	,55792	,280680	,079	-,161	,181	-1,045	,360
G6F3	180	,850	,075	,925	119,475	,66375	,266931	,071	-,619	,181	-,697	,360
G6F4	180	,850	,075	,925	129,450	,71917	,243549	,059	-1,005	,181	,244	,360
G6F5	180	,850	,075	,925	112,100	,62278	,259691	,067	-,414	,181	-,739	,360
G6F6	180	,850	,075	,925	134,425	,74681	,228870	,052	-1,248	,181	,944	,360
G6F7	180	,850	,075	,925	119,450	,66361	,265883	,071	-,742	,181	-,406	,360
G6F8	180	,850	,075	,925	103,300	,57389	,287117	,082	-,294	,181	-1,042	,360
G6F9	180	,850	,075	,925	87,725	,48736	,291374	,085	,004	,181	-1,127	,360
G7F1	180	,850	,075	,925	132,300	,73500	,214743	,046	-,878	,181	,009	,360
G7F2	180	,850	,075	,925	129,000	,71667	,228075	,052	-,762	,181	-,307	,360
G7F3	180	,850	,075	,925	124,850	,69361	,238933	,057	-,598	,181	-,613	,360
G7F4	180	,850	,075	,925	124,050	,68917	,247602	,061	-,711	,181	-,527	,360
G7F5	180	,850	,075	,925	131,025	,72792	,228110	,052	-,769	,181	-,563	,360
G7F6	180	,850	,075	,925	110,450	,61361	,271239	,074	-,333	,181	-,910	,360
G7F7	180	,850	,075	,925	125,850	,69917	,248837	,062	-,704	,181	-,644	,360
G7F8	180	,850	,075	,925	119,600	,66444	,267632	,072	-,567	,181	-,807	,360
G7F9	180	,850	,075	,925	119,800	,66556	,259743	,067	-,660	,181	-,516	,360
G7F10	180	,850	,075	,925	108,050	,60028	,265155	,070	-,356	,181	-,801	,360
G8F1	180	,850	,075	,925	124,400	,69111	,254315	,065	-,728	,181	-,494	,360
G8F2	180	,850	,075	,925	134,000	,74444	,216910	,047	-1,042	,181	,426	,360
G8F3	180	,850	,075	,925	132,775	,73764	,236382	,056	-1,054	,181	,226	,360
G8F4	180	,850	,075	,925	136,500	,75833	,227446	,052	-1,100	,181	,021	,360
G8F5	180	,850	,075	,925	138,950	,77194	,218036	,048	-1,305	,181	,923	,360
G8F6	180	,850	,075	,925	123,550	,68639	,254036	,065	-,862	,181	-,120	,360
G8F7	180	,850	,075	,925	117,350	,65194	,258628	,067	-,652	,181	-,421	,360
G8F8	180	,850	,075	,925	112,950	,62750	,267242	,071	-,478	,181	-,795	,360
G8F9	180	,850	,075	,925	100,275	,55708	,277965	,077	-,190	,181	-1,017	,360
G8F10	180	,850	,075	,925	105,550	,58639	,274617	,075	-,244	,181	-,952	,360

Table D.1: Descriptive statistics (Cont'd)

	N	Range	Min	Max	Sum	Mean	Std. Dev.	Vari-ance	Skewness		Kurtosis	
	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Std. Err.	Stat.	Std. Err.
G8F11	180	,850	,075	,925	125,775	,69875	,249249	,062	-,823	,181	-,189	,360
G8F12	180	,850	,075	,925	124,600	,69222	,264843	,070	-,815	,181	-,456	,360
G9F1	180	,850	,075	,925	112,450	,62472	,275526	,076	-,459	,181	-,871	,360
G9F2	180	,850	,075	,925	137,075	,76153	,218175	,048	-1,176	,181	,510	,360
G9F3	180	,850	,075	,925	132,150	,73417	,237390	,056	-1,038	,181	,181	,360
G9F4	180	,850	,075	,925	136,675	,75931	,209382	,044	-1,004	,181	-,045	,360
G9F5	180	,850	,075	,925	126,900	,70500	,259261	,067	-,845	,181	-,422	,360
G9F6	180	,850	,075	,925	113,750	,63194	,260761	,068	-,421	,181	-,785	,360
G9F7	180	,850	,075	,925	137,550	,76417	,233059	,054	-1,256	,181	,490	,360
G9F8	180	,850	,075	,925	132,250	,73472	,230275	,053	-,828	,181	-,614	,360
G9F9	180	,850	,075	,925	126,925	,70514	,268111	,072	-,933	,181	-,337	,360
G9F10	180	,850	,075	,925	116,450	,64694	,276812	,077	-,552	,181	-,865	,360
G9F11	180	,850	,075	,925	115,250	,64028	,263191	,069	-,485	,181	-,834	,360
G9F12	180	,850	,075	,925	132,400	,73556	,233775	,055	-1,047	,181	,189	,360
G10F1	180	,850	,075	,925	126,875	,70486	,240897	,058	-,821	,181	-,163	,360
G10F2	180	,850	,075	,925	128,900	,71611	,215149	,046	-,673	,181	-,452	,360
G10F3	180	,850	,075	,925	138,575	,76986	,224164	,050	-1,422	,181	1,352	,360
G10F4	180	,850	,075	,925	136,275	,75708	,218126	,048	-1,168	,181	,525	,360
G10F5	180	,850	,075	,925	114,400	,63556	,239456	,057	-,257	,181	-,868	,360
G10F6	180	,850	,075	,925	102,825	,57125	,274796	,076	-,221	,181	-,904	,360
G10F7	180	,850	,075	,925	110,925	,61625	,266580	,071	-,350	,181	-,860	,360
G10F8	180	,850	,075	,925	119,225	,66236	,260445	,068	-,534	,181	-,767	,360
G10F9	180	,850	,075	,925	112,650	,62583	,267879	,072	-,414	,181	-,834	,360
G10F10	180	,850	,075	,925	143,300	,79611	,211073	,045	-1,526	,181	1,305	,360
G10F11	180	,850	,075	,925	111,625	,62014	,273096	,075	-,443	,181	-,850	,360
G10F12	180	,850	,075	,925	123,500	,68611	,260977	,068	-,869	,181	-,204	,360
G11F1	180	,850	,075	,925	115,400	,64111	,246733	,061	-,299	,181	-,898	,360
G11F2	180	,850	,075	,925	105,500	,58611	,252822	,064	-,085	,181	-,860	,360
G11F3	180	,850	,075	,925	109,750	,60972	,259504	,067	-,197	,181	-,991	,360
G11F4	180	,850	,075	,925	109,100	,60611	,268929	,072	-,240	,181	-1,002	,360

Table D.1: Descriptive statistics (Cont'd)

	N	Range	Min	Max	Sum	Mean	Std. Dev.	Vari-ance	Skewness		Kurtosis	
	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Std. Err.	Stat.	Std. Err.
G11F5	180	,850	,075	,925	112,025	,62236	,265951	,071	-,247	,181	-1,123	,360
G11F6	180	,850	,075	,925	101,600	,56444	,282620	,080	-,128	,181	-1,100	,360
G11F7	180	,850	,075	,925	102,925	,57181	,270061	,073	-,131	,181	-1,002	,360
G11F8	180	,850	,075	,925	108,050	,60028	,277647	,077	-,275	,181	-1,082	,360
G12F1	180	,850	,075	,925	135,175	,75097	,234645	,055	-1,049	,181	-,178	,360
G12F2	180	,850	,075	,925	145,875	,81042	,188531	,036	-1,839	,181	3,462	,360
G12F3	180	,850	,075	,925	134,775	,74875	,225493	,051	-1,145	,181	,561	,360
G12F4	180	,850	,075	,925	140,750	,78194	,199074	,040	-1,271	,181	,908	,360
G12F5	180	,850	,075	,925	127,200	,70667	,250301	,063	-,846	,181	-,249	,360
G12F6	180	,850	,075	,925	135,275	,75153	,208130	,043	-,978	,181	-,005	,360
G12F7	180	,850	,075	,925	128,075	,71153	,244626	,060	-,852	,181	-,277	,360
G12F8	180	,850	,075	,925	146,825	,81569	,184603	,034	-1,687	,181	2,132	,360
G12F9	180	,850	,075	,925	146,950	,81639	,174036	,030	-1,666	,181	2,397	,360
G12F10	180	,850	,075	,925	136,450	,75806	,227410	,052	-1,278	,181	,814	,360
G12F11	180	,850	,075	,925	126,100	,70056	,244934	,060	-,704	,181	-,731	,360
G12F12	180	,850	,075	,925	125,200	,69556	,261604	,068	-,788	,181	-,488	,360
G13F1	180	,850	,075	,925	131,575	,73097	,246234	,061	-,965	,181	-,147	,360
G13F2	180	,850	,075	,925	143,800	,79889	,207873	,043	-1,641	,181	2,067	,360
G13F3	180	,850	,075	,925	142,075	,78931	,218058	,048	-1,562	,181	1,590	,360
G13F4	180	,850	,075	,925	133,000	,73889	,239285	,057	-1,115	,181	,297	,360
G13F5	180	,850	,075	,925	122,200	,67889	,263872	,070	-,819	,181	-,289	,360
G13F6	180	,850	,075	,925	121,125	,67292	,268672	,072	-,654	,181	-,733	,360
G13F7	180	,850	,075	,925	128,675	,71486	,252470	,064	-,931	,181	-,225	,360
G13F8	180	,850	,075	,925	124,650	,69250	,263569	,069	-,843	,181	-,337	,360
G13F9	180	,850	,075	,925	141,650	,78694	,216280	,047	-1,484	,181	1,400	,360
G13F10	180	,850	,075	,925	139,650	,77583	,214015	,046	-1,391	,181	1,269	,360
G13F11	180	,850	,075	,925	127,600	,70889	,258158	,067	-,917	,181	-,167	,360
G14F1	180	,850	,075	,925	119,275	,66264	,255737	,065	-,533	,181	-,744	,360
G14F2	180	,850	,075	,925	131,550	,73083	,224870	,051	-,863	,181	-,106	,360
G14F3	180	,850	,075	,925	140,250	,77917	,207497	,043	-1,595	,181	2,423	,360

Table D.1: Descriptive statistics (Cont'd)

	N	Range	Min	Max	Sum	Mean	Std. Dev.	Vari- ance	Skewness		Kurtosis	
	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Std. Err.	Stat.	Std. Err.
G14F4	180	,850	,075	,925	129,275	,71819	,221470	,049	-,743	,181	-,211	,360
G14F5	180	,850	,075	,925	143,375	,79653	,191724	,037	-1,593	,181	2,332	,360
G14F6	180	,850	,075	,925	132,925	,73847	,231046	,053	-1,154	,181	,583	,360
G14F7	180	,850	,075	,925	145,850	,81028	,192887	,037	-1,885	,181	3,458	,360
G14F8	180	,850	,075	,925	140,850	,78250	,210710	,044	-1,360	,181	1,051	,360
G14F9	180	,850	,075	,925	130,400	,72444	,247797	,061	-1,000	,181	-,017	,360
G14F10	180	,850	,075	,925	131,750	,73194	,249637	,062	-1,161	,181	,469	,360
G15F1	180	,850	,075	,925	140,150	,77861	,198319	,039	-1,241	,181	,877	,360
G15F2	180	,850	,075	,925	136,875	,76042	,211833	,045	-1,056	,181	,184	,360
G15F3	180	,850	,075	,925	145,800	,81000	,185670	,034	-1,599	,181	1,854	,360
G15F4	180	,850	,075	,925	143,675	,79819	,189954	,036	-1,356	,181	,976	,360
G15F5	180	,850	,075	,925	138,775	,77097	,206260	,043	-1,109	,181	,188	,360
G15F6	180	,850	,075	,925	107,750	,59861	,262731	,069	-,276	,181	-,920	,360
G15F7	180	,850	,075	,925	118,775	,65986	,243311	,059	-,518	,181	-,591	,360
G15F8	180	,850	,075	,925	137,725	,76514	,223349	,050	-1,332	,181	1,032	,360
G15F9	180	,850	,075	,925	132,050	,73361	,245779	,060	-1,034	,181	,071	,360
G16F1	180	,850	,075	,925	142,450	,79139	,195503	,038	-1,412	,181	1,376	,360
G16F2	180	,850	,075	,925	141,675	,78708	,202696	,041	-1,251	,181	,651	,360
G16F3	180	,850	,075	,925	146,600	,81444	,186839	,035	-1,681	,181	2,288	,360
G16F4	180	,850	,075	,925	143,600	,79778	,197775	,039	-1,417	,181	1,206	,360
G16F5	180	,850	,075	,925	144,000	,80000	,210712	,044	-1,700	,181	2,182	,360
G16F6	180	,850	,075	,925	123,825	,68792	,241554	,058	-,624	,181	-,609	,360
G16F7	180	,850	,075	,925	127,400	,70778	,254187	,065	-,883	,181	-,269	,360
G16F8	180	,850	,075	,925	143,375	,79653	,225206	,051	-1,591	,181	1,427	,360
G16F9	180	,850	,075	,925	122,275	,67931	,256369	,066	-,662	,181	-,614	,360
G16F10	180	,850	,075	,925	137,325	,76292	,216860	,047	-1,225	,181	,794	,360
Valid N (listwise)	180											

APPENDIX E

THE MEASUREMENT MODEL EQUATIONS BY LISREL

Table E.1: The measurement model equations by Lisrel

Number of Iterations =328		
LISREL Estimates (Maximum Likelihood)		
Measurement Equations		
G1F1 = 1.00*G1, Errorvar.= 0.024 , R^2 = 0.48		
	(0.0028)	
	8.61	
G1F2 = 0.75*G1, Errorvar.= 0.017 , R^2 = 0.43		
	(0.091)	(0.0019)
	8.24	8.77
G1F3 = 0.75*G1, Errorvar.= 0.014 , R^2 = 0.47		
	(0.088)	(0.0017)
	8.56	8.66
G1F4 = 0.91*G1, Errorvar.= 0.037 , R^2 = 0.34		
	(0.12)	(0.0041)
	7.32	9.00
G1F5 = 1.07*G1, Errorvar.= 0.026 , R^2 = 0.50		
	(0.12)	(0.0030)
	8.85	8.54
G1F6 = 1.07*G1, Errorvar.= 0.033 , R^2 = 0.44		
	(0.13)	(0.0038)
	8.32	8.75

Table E.1: The measurement model equations by Lisrel (Cont'd)

G1F7 = 1.12*G1, Errorvar.= 0.041 , R^2 = 0.41
(0.14) (0.0046)
8.07 8.82
G1F8 = 1.01*G1, Errorvar.= 0.032 , R^2 = 0.42
(0.12) (0.0036)
8.11 8.81
G1F9 = 1.15*G1, Errorvar.= 0.043 , R^2 = 0.41
(0.14) (0.0049)
8.04 8.83
G1F10 = 0.71*G1, Errorvar.= 0.024 , R^2 = 0.32
(0.099) (0.0027)
7.13 9.03
G1F11 = 0.77*G1, Errorvar.= 0.016 , R^2 = 0.46
(0.090) (0.0018)
8.52 8.68
G1F12 = 0.90*G1, Errorvar.= 0.031 , R^2 = 0.37
(0.12) (0.0035)
7.65 8.93
G2F1 = 1.00*G2, Errorvar.= 0.030 , R^2 = 0.45
(0.0035)
8.70
G2F2 = 1.11*G2, Errorvar.= 0.024 , R^2 = 0.56
(0.086) (0.0029)
12.93 8.30
G2F3 = 1.01*G2, Errorvar.= 0.024 , R^2 = 0.51
(0.12) (0.0029)
8.54 8.55
G2F4 = 0.94*G2, Errorvar.= 0.026 , R^2 = 0.45
(0.12) (0.0030)
8.08 8.73
G2F5 = 1.24*G2, Errorvar.= 0.039 , R^2 = 0.49
(0.15) (0.0045)
8.41 8.64

Table E.1: The measurement model equations by Lisrel (Cont'd)

G2F6 = 1.23*G2, Errorvar.= 0.023 , R^2 = 0.62
(0.13) (0.0029)
9.29 8.08
G2F7 = 1.35*G2, Errorvar.= 0.024 , R^2 = 0.65
(0.14) (0.0031)
9.47 7.89
G2F8 = 1.10*G2, Errorvar.= 0.044 , R^2 = 0.40
(0.14) (0.0050)
7.67 8.85
G2F9 = 1.07*G2, Errorvar.= 0.034 , R^2 = 0.45
(0.13) (0.0039)
8.13 8.75
G2F10 = 0.93*G2, Errorvar.= 0.047 , R^2 = 0.31
(0.14) (0.0052)
6.82 9.06
G3F1 = 1.00*G3, Errorvar.= 0.031 , R^2 = 0.36
(0.0034)
8.96
G3F2 = 0.73*G3, Errorvar.= 0.022 , R^2 = 0.29
(0.12) (0.0024)
6.20 9.09
G3F3 = 1.00*G3, Errorvar.= 0.028 , R^2 = 0.37
(0.15) (0.0032)
6.82 8.92
G3F4 = 1.18*G3, Errorvar.= 0.017 , R^2 = 0.58
(0.15) (0.0021)
7.96 8.22
G3F5 = 1.32*G3, Errorvar.= 0.032 , R^2 = 0.48
(0.18) (0.0037)
7.46 8.63
G3F6 = 1.12*G3, Errorvar.= 0.031 , R^2 = 0.41
(0.16) (0.0036)
7.04 8.80

Table E.1: The measurement model equations by Lisrel (Cont'd)

G3F7 = 1.20*G3, Errorvar.= 0.029 , R^2 = 0.46
(0.16) (0.0034)
7.36 8.66
G3F8 = 1.28*G3, Errorvar.= 0.023 , R^2 = 0.55
(0.16) (0.0027)
7.83 8.34
G3F9 = 1.28*G3, Errorvar.= 0.024 , R^2 = 0.54
(0.17) (0.0029)
7.78 8.39
G4F1 = 1.00*G4, Errorvar.= 0.040 , R^2 = 0.32
(0.0044)
9.13
G4F2 = 1.31*G4, Errorvar.= 0.046 , R^2 = 0.42
(0.15) (0.0051)
8.69 8.97
G4F3 = 0.95*G4, Errorvar.= 0.019 , R^2 = 0.47
(0.13) (0.0022)
7.19 8.85
G4F4 = 1.07*G4, Errorvar.= 0.024 , R^2 = 0.48
(0.15) (0.0027)
7.23 8.83
G4F5 = 1.53*G4, Errorvar.= 0.027 , R^2 = 0.62
(0.20) (0.0032)
7.84 8.32
G4F6 = 1.39*G4, Errorvar.= 0.032 , R^2 = 0.53
(0.19) (0.0037)
7.47 8.65
G4F7 = 1.10*G4, Errorvar.= 0.021 , R^2 = 0.52
(0.15) (0.0025)
7.41 8.69
G4F8 = 1.17*G4, Errorvar.= 0.020 , R^2 = 0.57
(0.15) (0.0023)
7.61 8.57

Table E.1: The measurement model equations by Lisrel (Cont'd)

G4F9 = 1.34*G4, Errorvar.= 0.028 , R^2 = 0.55
(0.18) (0.0032)
7.56 8.61
G4F10 = 1.17*G4, Errorvar.= 0.025 , R^2 = 0.52
(0.16) (0.0028)
7.40 8.73
G5F1 = 1.00*G5, Errorvar.= 0.033 , R^2 = 0.51
(0.0037)
8.91
G5F2 = 0.98*G5, Errorvar.= 0.038 , R^2 = 0.47
(0.11) (0.0042)
9.01 8.99
G5F3 = 1.12*G5, Errorvar.= 0.038 , R^2 = 0.54
(0.12) (0.0042)
9.65 8.84
G5F4 = 0.98*G5, Errorvar.= 0.025 , R^2 = 0.57
(0.099) (0.0029)
9.92 8.76
G5F5 = 1.06*G5, Errorvar.= 0.033 , R^2 = 0.54
(0.11) (0.0038)
9.63 8.70
G5F6 = 0.86*G5, Errorvar.= 0.033 , R^2 = 0.44
(0.099) (0.0036)
8.72 9.04
G5F7 = 1.08*G5, Errorvar.= 0.032 , R^2 = 0.56
(0.11) (0.0036)
9.84 8.79
G5F8 = 1.26*G5, Errorvar.= 0.031 , R^2 = 0.64
(0.12) (0.0037)
10.49 8.36
G5F9 = 1.13*G5, Errorvar.= 0.046 , R^2 = 0.49
(0.12) (0.0051)
9.20 8.95

Table E.1: The measurement model equations by Lisrel (Cont'd)

G5F10 = 1.06*G5, Errorvar.= 0.036 , R^2 = 0.52
(0.11) (0.0040)
9.50 8.88
G5F11 = 1.10*G5, Errorvar.= 0.031 , R^2 = 0.58
(0.11) (0.0035)
9.98 8.74
G5F12 = 1.16*G5, Errorvar.= 0.037 , R^2 = 0.56
(0.12) (0.0042)
9.84 8.79
G6F1 = 1.00*G6, Errorvar.= 0.027 , R^2 = 0.65
(0.0033)
8.36
G6F2 = 0.97*G6, Errorvar.= 0.030 , R^2 = 0.61
(0.081) (0.0036)
11.96 8.50
G6F3 = 0.91*G6, Errorvar.= 0.028 , R^2 = 0.60
(0.077) (0.0033)
11.78 8.54
G6F4 = 0.82*G6, Errorvar.= 0.025 , R^2 = 0.58
(0.071) (0.0029)
11.48 8.66
G6F5 = 0.94*G6, Errorvar.= 0.022 , R^2 = 0.68
(0.073) (0.0026)
12.84 8.23
G6F6 = 0.73*G6, Errorvar.= 0.025 , R^2 = 0.53
(0.068) (0.0028)
10.84 8.81
G6F7 = 0.94*G6, Errorvar.= 0.026 , R^2 = 0.64
(0.076) (0.0030)
12.27 8.44
G6F8 = 1.06*G6, Errorvar.= 0.024 , R^2 = 0.71
(0.081) (0.0030)
13.22 8.05

Table E.1: The measurement model equations by Lisrel (Cont’d)

G6F9 = 0.91*G6, Errorvar.= 0.042 , R^2 = 0.50
(0.087) (0.0047)
10.50 8.87
G7F1 = 1.00*G7, Errorvar.= 0.025 , R^2 = 0.46
(0.0028)
8.95
G7F2 = 1.10*G7, Errorvar.= 0.026 , R^2 = 0.49
(0.090) (0.0030)
12.23 8.88
G7F3 = 1.29*G7, Errorvar.= 0.022 , R^2 = 0.61
(0.13) (0.0026)
9.58 8.51
G7F4 = 1.43*G7, Errorvar.= 0.018 , R^2 = 0.70
(0.14) (0.0023)
10.14 8.01
G7F5 = 1.22*G7, Errorvar.= 0.021 , R^2 = 0.60
(0.13) (0.0025)
9.47 8.48
G7F6 = 1.56*G7, Errorvar.= 0.022 , R^2 = 0.69
(0.15) (0.0028)
10.11 8.11
G7F7 = 1.33*G7, Errorvar.= 0.025 , R^2 = 0.60
(0.14) (0.0029)
9.47 8.57
G7F8 = 1.54*G7, Errorvar.= 0.022 , R^2 = 0.70
(0.15) (0.0027)
10.12 8.09
G7F9 = 1.44*G7, Errorvar.= 0.024 , R^2 = 0.65
(0.15) (0.0028)
9.82 8.34
G7F10 = 1.23*G7, Errorvar.= 0.039 , R^2 = 0.45
(0.15) (0.0043)
8.32 8.93

Table E.1: The measurement model equations by Lisrel (Cont'd)

G8F1 = 1.00*G8, Errorvar.= 0.028 , R² = 0.56
(0.0032)
8.86
G8F2 = 0.90*G8, Errorvar.= 0.017 , R² = 0.63
(0.081) (0.0020)
11.13 8.64
G8F3 = 0.95*G8, Errorvar.= 0.023 , R² = 0.58
(0.089) (0.0027)
10.63 8.81
G8F4 = 0.97*G8, Errorvar.= 0.017 , R² = 0.67
(0.073) (0.0020)
13.27 8.60
G8F5 = 0.89*G8, Errorvar.= 0.019 , R² = 0.60
(0.082) (0.0022)
10.83 8.74
G8F6 = 1.02*G8, Errorvar.= 0.027 , R² = 0.58
(0.096) (0.0030)
10.65 8.83
G8F7 = 1.06*G8, Errorvar.= 0.026 , R² = 0.61
(0.097) (0.0030)
10.93 8.71
G8F8 = 1.10*G8, Errorvar.= 0.026 , R² = 0.63
(0.099) (0.0030)
11.06 8.72
G8F9 = 1.12*G8, Errorvar.= 0.031 , R² = 0.60
(0.10) (0.0035)
10.75 8.82
G8F10 = 1.04*G8, Errorvar.= 0.035 , R² = 0.53
(0.10) (0.0039)
10.06 8.92
G8F11 = 1.04*G8, Errorvar.= 0.023 , R² = 0.63
(0.093) (0.0026)
11.12 8.70

Table E.1: The measurement model equations by Lisrel (Cont'd)

G8F12 = 1.09*G8, Errorvar.= 0.027 , R^2 = 0.62
(0.099) (0.0031)
10.98 8.74
G9F1 = 1.00*G9, Errorvar.= 0.036 , R^2 = 0.52
(0.0041)
8.95
G9F2 = 0.87*G9, Errorvar.= 0.018 , R^2 = 0.63
(0.082) (0.0021)
10.54 8.62
G9F3 = 0.93*G9, Errorvar.= 0.021 , R^2 = 0.62
(0.089) (0.0024)
10.53 8.63
G9F4 = 0.84*G9, Errorvar.= 0.016 , R^2 = 0.63
(0.079) (0.0019)
10.59 8.59
G9F5 = 1.01*G9, Errorvar.= 0.027 , R^2 = 0.60
(0.098) (0.0031)
10.32 8.76
G9F6 = 1.05*G9, Errorvar.= 0.024 , R^2 = 0.64
(0.098) (0.0028)
10.68 8.62
G9F7 = 0.88*G9, Errorvar.= 0.024 , R^2 = 0.56
(0.088) (0.0027)
9.99 8.84
G9F8 = 0.87*G9, Errorvar.= 0.022 , R^2 = 0.57
(0.086) (0.0025)
10.07 8.88
G9F9 = 1.09*G9, Errorvar.= 0.025 , R^2 = 0.65
(0.10) (0.0029)
10.77 8.69
G9F10 = 1.10*G9, Errorvar.= 0.028 , R^2 = 0.63
(0.10) (0.0032)
10.59 8.84

Table E.1: The measurement model equations by Lisrel (Cont'd)

G9F11 = 0.99*G9, Errorvar.= 0.030 , R^2 = 0.57
(0.099) (0.0034)
10.01 8.86
G9F12 = 0.87*G9, Errorvar.= 0.025 , R^2 = 0.54
(0.088) (0.0028)
9.81 8.90
G10F1 = 1.00*G10, Errorvar.= 0.025 , R^2 = 0.57
(0.0028)
8.72
G10F2 = 0.67*G10, Errorvar.= 0.032 , R^2 = 0.32
(0.087) (0.0034)
7.65 9.20
G10F3 = 0.79*G10, Errorvar.= 0.029 , R^2 = 0.42
(0.090) (0.0032)
8.84 9.06
G10F4 = 0.78*G10, Errorvar.= 0.027 , R^2 = 0.42
(0.087) (0.0030)
8.93 9.05
G10F5 = 0.83*G10, Errorvar.= 0.035 , R^2 = 0.40
(0.096) (0.0038)
8.59 9.10
G10F6 = 1.03*G10, Errorvar.= 0.040 , R^2 = 0.47
(0.11) (0.0045)
9.44 8.95
G10F7 = 1.19*G10, Errorvar.= 0.023 , R^2 = 0.67
(0.10) (0.0027)
11.63 8.37
G10F8 = 1.13*G10, Errorvar.= 0.025 , R^2 = 0.63
(0.10) (0.0030)
11.15 8.49
G10F9 = 1.19*G10, Errorvar.= 0.025 , R^2 = 0.65
(0.10) (0.0030)
11.41 8.43

Table E.1: The measurement model equations by Lisrel (Cont'd)

G10F10 = 0.64*G10, Errorvar.= 0.031 , R^2 = 0.30
(0.086) (0.0034)
7.44 9.22
G10F11 = 1.09*G10, Errorvar.= 0.035 , R^2 = 0.53
(0.11) (0.0040)
10.11 8.84
G10F12 = 1.10*G10, Errorvar.= 0.028 , R^2 = 0.59
(0.10) (0.0032)
10.77 8.67
G11F1 = 1.00*G11, Errorvar.= 0.023 , R^2 = 0.63
(0.0026)
8.88
G11F2 = 1.05*G11, Errorvar.= 0.022 , R^2 = 0.66
(0.068) (0.0025)
15.35 8.80
G11F3 = 1.23*G11, Errorvar.= 0.0092 , R^2 = 0.86
(0.082) (0.0013)
15.09 7.30
G11F4 = 1.31*G11, Errorvar.= 0.0068 , R^2 = 0.91
(0.084) (0.0011)
15.64 6.19
G11F5 = 1.23*G11, Errorvar.= 0.013 , R^2 = 0.82
(0.085) (0.0016)
14.55 7.90
G11F6 = 1.25*G11, Errorvar.= 0.020 , R^2 = 0.75
(0.092) (0.0024)
13.56 8.48
G11F7 = 1.10*G11, Errorvar.= 0.027 , R^2 = 0.64
(0.091) (0.0030)
12.14 8.88
G11F8 = 0.92*G11, Errorvar.= 0.045 , R^2 = 0.42
(0.099) (0.0048)
9.37 9.21

Table E.1: The measurement model equations by Lisrel (Cont'd)

G12F1 = 1.00*G12, Errorvar.= 0.017 , R^2 = 0.69
(0.0020)
8.54
G12F2 = 0.66*G12, Errorvar.= 0.019 , R^2 = 0.47
(0.064) (0.0021)
10.39 9.09
G12F3 = 0.88*G12, Errorvar.= 0.021 , R^2 = 0.58
(0.074) (0.0024)
11.96 8.84
G12F4 = 0.82*G12, Errorvar.= 0.014 , R^2 = 0.64
(0.063) (0.0016)
12.92 8.72
G12F5 = 1.09*G12, Errorvar.= 0.018 , R^2 = 0.71
(0.077) (0.0021)
14.08 8.42
G12F6 = 0.78*G12, Errorvar.= 0.020 , R^2 = 0.53
(0.069) (0.0022)
11.33 8.98
G12F7 = 0.98*G12, Errorvar.= 0.024 , R^2 = 0.61
(0.079) (0.0027)
12.42 8.82
G12F8 = 0.59*G12, Errorvar.= 0.021 , R^2 = 0.39
(0.064) (0.0023)
9.21 9.17
G12F9 = 0.66*G12, Errorvar.= 0.013 , R^2 = 0.55
(0.057) (0.0015)
11.55 8.95
G12F10 = 0.74*G12, Errorvar.= 0.031 , R^2 = 0.40
(0.079) (0.0034)
9.42 9.18
G12F11 = 0.98*G12, Errorvar.= 0.024 , R^2 = 0.61
(0.079) (0.0027)
12.43 8.82

Table E.1: The measurement model equations by Lisrel (Cont'd)

G12F12 = 1.01*G12, Errorvar.= 0.030 , R^2 = 0.56
(0.086) (0.0033)
11.79 8.92
G13F1 = 1.00*G13, Errorvar.= 0.022 , R^2 = 0.63
(0.0026)
8.72
G13F2 = 0.83*G13, Errorvar.= 0.016 , R^2 = 0.62
(0.070) (0.0019)
11.86 8.76
G13F3 = 0.91*G13, Errorvar.= 0.016 , R^2 = 0.67
(0.073) (0.0019)
12.49 8.56
G13F4 = 0.97*G13, Errorvar.= 0.021 , R^2 = 0.63
(0.081) (0.0024)
12.03 8.73
G13F5 = 0.91*G13, Errorvar.= 0.038 , R^2 = 0.45
(0.093) (0.0042)
9.76 9.10
G13F6 = 1.05*G13, Errorvar.= 0.030 , R^2 = 0.59
(0.092) (0.0034)
11.45 8.83
G13F7 = 1.07*G13, Errorvar.= 0.020 , R^2 = 0.69
(0.084) (0.0023)
12.78 8.46
G13F8 = 1.10*G13, Errorvar.= 0.024 , R^2 = 0.66
(0.088) (0.0027)
12.44 8.62
G13F9 = 0.87*G13, Errorvar.= 0.018 , R^2 = 0.62
(0.073) (0.0021)
11.90 8.61
G13F10 = 0.90*G13, Errorvar.= 0.015 , R^2 = 0.67
(0.071) (0.0018)
12.56 8.58

Table E.1: The measurement model equations by Lisrel (Cont'd)

G13F11 = 1.02*G13, Errorvar.= 0.027 , R^2 = 0.60
(0.088) (0.0031)
11.60 8.69
G14F1 = 1.00*G14, Errorvar.= 0.025 , R^2 = 0.62
(0.0029)
8.69
G14F2 = 0.89*G14, Errorvar.= 0.018 , R^2 = 0.64
(0.075) (0.0021)
11.95 8.63
G14F3 = 0.76*G14, Errorvar.= 0.020 , R^2 = 0.54
(0.070) (0.0022)
10.78 8.90
G14F4 = 0.77*G14, Errorvar.= 0.025 , R^2 = 0.49
(0.076) (0.0028)
10.14 9.01
G14F5 = 0.71*G14, Errorvar.= 0.016 , R^2 = 0.56
(0.065) (0.0018)
10.99 8.84
G14F6 = 0.75*G14, Errorvar.= 0.030 , R^2 = 0.43
(0.080) (0.0033)
9.38 9.10
G14F7 = 0.74*G14, Errorvar.= 0.015 , R^2 = 0.59
(0.065) (0.0017)
11.36 8.76
G14F8 = 0.80*G14, Errorvar.= 0.019 , R^2 = 0.58
(0.071) (0.0021)
11.21 8.82
G14F9 = 1.04*G14, Errorvar.= 0.017 , R^2 = 0.72
(0.081) (0.0021)
12.95 8.25
G14F10 = 0.99*G14, Errorvar.= 0.023 , R^2 = 0.63
(0.083) (0.0027)
11.87 8.65

Table E.1: The measurement model equations by Lisrel (Cont'd)

G15F1 = 1.00*G15, Errorvar.= 0.019 , R^2 = 0.53	
	(0.0021)
	8.70
G15F2 = 1.18*G15, Errorvar.= 0.016 , R^2 = 0.65	
(0.11)	(0.0019)
10.75	8.18
G15F3 = 0.91*G15, Errorvar.= 0.017 , R^2 = 0.50	
(0.097)	(0.0020)
9.38	8.75
G15F4 = 1.02*G15, Errorvar.= 0.014 , R^2 = 0.61	
(0.099)	(0.0017)
10.35	8.41
G15F5 = 1.03*G15, Errorvar.= 0.020 , R^2 = 0.52	
(0.11)	(0.0024)
9.53	8.71
G15F6 = 1.08*G15, Errorvar.= 0.045 , R^2 = 0.35	
(0.14)	(0.0049)
7.83	9.08
G15F7 = 1.09*G15, Errorvar.= 0.034 , R^2 = 0.42	
(0.13)	(0.0038)
8.53	8.97
G15F8 = 0.96*G15, Errorvar.= 0.031 , R^2 = 0.39	
(0.12)	(0.0034)
8.18	9.04
G15F9 = 1.26*G15, Errorvar.= 0.028 , R^2 = 0.54	
(0.13)	(0.0032)
9.78	8.65
G16F1 = 1.00*G16, Errorvar.= 0.020 , R^2 = 0.48	
	(0.0022)
	8.79
G16F2 = 1.18*G16, Errorvar.= 0.015 , R^2 = 0.63	
(0.12)	(0.0019)
9.93	8.26

Table E.1: The measurement model equations by Lisrel (Cont'd)

G16F3 = 1.09*G16, Errorvar.= 0.013 , R^2 = 0.63
(0.11) (0.0016)
9.97 8.17
G16F4 = 1.10*G16, Errorvar.= 0.017 , R^2 = 0.57
(0.12) (0.0020)
9.48 8.44
G16F5 = 1.23*G16, Errorvar.= 0.016 , R^2 = 0.63
(0.12) (0.0020)
9.95 8.24
G16F6 = 1.15*G16, Errorvar.= 0.034 , R^2 = 0.42
(0.14) (0.0038)
8.21 8.93
G16F7 = 1.42*G16, Errorvar.= 0.027 , R^2 = 0.58
(0.15) (0.0032)
9.53 8.49
G16F8 = 0.99*G16, Errorvar.= 0.033 , R^2 = 0.35
(0.13) (0.0036)
7.56 9.07
G16F9 = 1.15*G16, Errorvar.= 0.041 , R^2 = 0.37
(0.15) (0.0046)
7.73 9.03
G16F10 = 1.19*G16, Errorvar.= 0.021 , R^2 = 0.55
(0.13) (0.0024)
9.37 8.57

APPENDIX F

THE STRUCTURAL MODEL EQUATIONS BY LISREL

Table F.1: The structural model equations by Lisrel

Number of Iterations =328
LISREL Estimates (Maximum Likelihood)
Structural Equations
G1 = 0.12*SP, Errorvar.= 0.0086 , R^2 = 0.62
(0.014) (0.0018)
8.70 4.79
G2 = 0.13*SP, Errorvar.= 0.0076 , R^2 = 0.69
(0.015) (0.0017)
8.69 4.45
G3 = 0.11*SP, Errorvar.= 0.0039 , R^2 = 0.77
(0.014) (0.0010)
7.96 3.70
G4 = 0.13*SP, Errorvar.= 0.0032 , R^2 = 0.83
(0.016) (0.00091)
7.76 3.49
G5 = 0.16*SP, Errorvar.= 0.0097 , R^2 = 0.72
(0.016) (0.0019)
9.63 5.01
G6 = 0.19*SP, Errorvar.= 0.014 , R^2 = 0.73
(0.018) (0.0024)
11.02 5.68

Table F.1: The structural model equations by Lisrel (Cont'd)

G7 = 0.12*SP, Errorvar.= 0.0065 , R^2 = 0.69
(0.014) (0.0014)
8.91 4.70
G8 = 0.17*SP, Errorvar.= 0.0068 , R^2 = 0.81
(0.016) (0.0013)
10.67 5.02
G9 = 0.19*SP, Errorvar.= 0.0043 , R^2 = 0.89
(0.018) (0.0011)
10.56 4.05
G10 = 0.17*SP, Errorvar.= 0.0040 , R^2 = 0.88
(0.015) (0.00096)
11.12 4.15
G11 = 0.13*SP, Errorvar.= 0.022 , R^2 = 0.43
(0.015) (0.0035)
8.41 6.20
G12 = 0.18*SP, Errorvar.= 0.0051 , R^2 = 0.87
(0.014) (0.00099)
12.50 5.15
G13 = 0.17*SP, Errorvar.= 0.0089 , R^2 = 0.77
(0.015) (0.0016)
11.15 5.62
G14 = 0.19*SP, Errorvar.= 0.0046 , R^2 = 0.89
(0.016) (0.0010)
11.78 4.43
G15 = 0.13*SP, Errorvar.= 0.0028 , R^2 = 0.87
(0.013) (0.00071)
10.47 3.90
G16 = 0.12*SP, Errorvar.= 0.0047 , R^2 = 0.74
(0.013) (0.0010)
9.36 4.62

APPENDIX G

THE FILLED FORMS FOR CASE STUDIES #1 TO #11

Table G.1: The filled forms for case studies

VARIABLES AFFECTING SAFETY PERFORMANCE	**Evaluation of variables (scale: 0-100)** **0**: Conformity is minimum **100**: Conformity is maximum **NA**: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
1) SCAFFOLDINGS AND WORKING PLATFORMS											
1.1 Installation, operation and disassembly plan for the scaffolding are present.	100	90	99	50	90	0	0	30	65	75	75
1.2 Defective and worn fasteners are not used in scaffolding system.	87	60	90	70	75	80	30	65	80	70	70
1.3 Fastening and supporting against horizontal and vertical forces are performed properly.	90	55	65	60	65	50	40	70	85	65	65
1.4 Rubbish and waste material on scaffoldings and platforms are cleared not to block people to pass.	75	70	92	90	60	70	70	75	45	90	90
1.5 Guard rails, intermediate rails, toe boards, screens and plankings comply with the standards.	90	75	88	80	80	75	0	50	75	80	80
1.6 Gateways with proper system are present at scaffoldings.	75	60	75	50	80	0	20	60	100	50	50
1.7 Preventive measures (barrier/warning notices) are taken for incomplete/unsafe scaffolds.	50	10	35	0	20	30	0	45	100	85	85
1.8 Scaffolding and working platforms are controlled/inspected before use.	60	50	66	50	60	50	0	70	90	65	65

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	Evaluation of variables (scale: 0-100) 0: Conformity is minimum 100: Conformity is maximum NA: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
1.9 Sign boards are hung indicating the maximum load capacity that scaffoldings can bear at proper and visible places.	50	0	35	0	0	40	0	60	70	30	30
1.10 Scaffoldings and working platforms are not overloaded.	85	90	90	70	95	60	0	65	50	80	80
1.11 Assembly and disassembly operations are performed by experienced/trained people.	95	80	98	100	95	65	50	75	100	90	90
1.12 Proper personal protective equipment (PPE) are used.	80	80	85	65	75	70	50	50	90	85	85
2) LADDERS AND STAIRS											
2.1 Ladders and stairs are made up of strong and non-defective material.	80	56	96	95	80	40	0	75	60	85	85
2.2 Equipment with undamaged rungs, arms or connection parts are used in ladders/stairs.	90	96	75	86	80	60	0	50	70	70	70
2.3 Ladders/stairs are based on firm and leveled foundation.	75	65	80	85	90	75	0	80	80	65	65
2.4 Ladders' bottom and top parts are fixed properly.	85	80	95	90	75	50	0	30	75	60	60
2.5 Ladders/stairs with missing parts are tagged.	50	10	25	0	50	30	0	45	75	60	60
2.6 Proper ladders are used for the job.	75	95	88	100	90	50	0	85	50	65	65
2.7 Ladders are positioned at the correct angle.	85	75	85	90	95	40	0	50	80	75	75
2.8 Ladders/stairs are in clean condition.	70	75	70	95	100	60	0	20	50	85	85
2.9 Ladders/stairs are positioned in a safe distance from vehicles, mobile cranes and electricity lines etc.	70	75	85	90	75	30	60	20	65	40	40

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	**Evaluation of variables (scale: 0-100)** **0**: Conformity is minimum **100**: Conformity is maximum **NA**: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
2.10 Ladders/stairs are daily inspected and maintained.	60	80	90	60	75	80	50	55	70	80	80
3) WORKING AT HEIGHT AND PROTECTION AGAINST FALLING											
3.1 Working at height is planned in advance and required organizations are made.	80	85	95	100	100	50	20	75	90	90	90
3.2 Barriers and warning signs are placed for open edges and holes.	90	65	95	0	0	55	0	80	85	70	70
3.3 Safety nets and air bags comply with the standards.	50	0	10	NA	NA	NA	NA	80	50	NA	NA
3.4 Guardrails, handrails or rails comply with the standards.	75	45	75	85	90	75	30	65	75	80	80
3.5 Employee's access to working places by inconvenient means and equipment is restricted.	85	80	99	80	60	50	60	40	75	50	50
3.6 Preventive measures against falling of hand tools and other materials are taken.	60	20	50	85	70	30	0	70	85	60	60
3.7 Access to the areas subject to falling objects is prevented and gateways with coverings are erected.	70	70	60	75	70	40	0	75	50	40	40
3.8 Safe working equipment used at heights are regularly inspected and maintained.	50	45	70	60	70	40	10	70	90	55	55
3.9 Proper personal protective equipment (PPE) are used.	70	80	80	75	78	60	70	60	85	80	80
4) LIGHTING AND ELECTRICITY											
4.1 Adequate illumination is supplied to working places, passageways and routes.	95	80	95	100	65	90	70	90	75	95	95

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	Evaluation of variables (scale: 0-100) **0**: Conformity is minimum **100**: Conformity is maximum **NA**: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
4.2 Auxiliary illumination system is present against electricity cuts.	70	80	95	0	0	50	60	50	0	50	50
4.3 Proper connectors are used (E.g.: connections with close-ended cables)	80	70	80	80	55	50	0	85	60	70	70
4.4 Proper residual current devices are used in the main and secondary electricity panels.	80	80	90	100	75	20	0	90	95	75	75
4.5 Panels, boards, control apparatus, etc. are stored in lockers or cabinets	85	70	86	85	50	90	50	80	50	60	60
4.6 Cabinets, panels and switches located in wet locations are enclosed with weather-proof enclosures.	65	55	75	85	70	90	60	75	60	30	30
4.7 Overhead lines are marked and appropriate measures are taken to prevent contact with them.	90	85	92	90	90	75	60	100	50	0	0
4.8 All of the hardware and connection works are done by authorized people.	80	80	91	70	85	90	80	75	65	80	80
4.9 Electrical danger posts and warning signs are present.	90	85	88	70	90	80	80	70	90	65	65
4.10 Proper personal protective equipment (PPE) are used.	85	80	91	80	85	75	60	65	80	80	80
5) HOUSEKEEPING, ORDER AND TIDINESS											
5.1 Sufficient space is present for working areas.	100	80	99	60	100	60	40	90	75	60	60
5.2 Appropriate places are provided where employees can relax	90	90	90	75	90	50	30	80	50	60	60
5.3 Garbage is collected regularly and dumped carefully.	85	70	85	50	80	50	20	60	75	55	55
5.4 Preventive measures (barriers/warning signs) are taken for slippery surfaces.	60	50	45	70	60	30	0	40	90	50	50

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	Evaluation of variables (scale: 0-100) 0: Conformity is minimum 100: Conformity is maximum NA: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
5.5 Construction site is fenced properly to prevent unauthorized entry.	95	90	90	75	95	40	0	75	100	80	80
5.6 Working areas are cleared from waste and materials with sharp and keen edges (E.g.: form with nails).	80	85	70	55	95	50	0	70	80	65	65
5.7 Isolation tapes and warning notices are provided for plant and equipment temporarily suspended for work execution.	75	10	55	50	90	60	40	70	75	60	60
5.8 The sanitary facilities are adequate and comply with the hygiene requirements.	90	70	80	90	100	75	60	75	90	50	50
5.9 Sufficient amount of potable water is provided.	100	75	90	100	100	70	75	90	100	70	70
5.10 Chemical and biological analyzes are performed for potable water.	100	80	95	80	100	25	10	85	90	50	50
5.11 Measurement and control of harmful dusts, gases, fumes, vapors, vibration, noise, pollution are performed.	85	80	95	80	100	50	10	60	70	70	70
5.12 Necessary measures are taken for protection of workers from too hot and cold.	90	65	90	90	80	75	40	80	65	50	50
6) PERSONAL PROTECTIVE EQUIPMENT (PPE)											
6.1 Personal protective equipments have appropriate standards.	90	80	100	100	100	85	80	90	100	80	80
6.2 Workers can access personal protective equipments easily.	80	100	90	80	100	70	50	85	95	70	70
6.3 Adequate amounts of personal protective equipments are provided.	90	90	100	90	100	75	60	80	90	85	85

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	Evaluation of variables (scale: 0-100) **0**: Conformity is minimum **100**: Conformity is maximum **NA**: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
6.4 Personal protective equipments are used by workers correctly and properly.	75	95	99	75	60	75	60	65	85	80	80
6.5 Personal protective equipments are inspected before each use.	85	85	90	95	80	40	50	70	65	80	80
6.6 Damaged personal protective equipments are not used.	90	85	90	80	70	60	50	70	70	75	75
6.7 Adequate instruction and practical training is provided to workers for use and maintenance.	80	64	75	80	90	65	50	55	70	75	75
6.8 Personal protective equipments are regularly maintained and kept clean.	85	65	80	95	95	50	50	50	80	70	70
6.9 Use of personal protective equipment is encouraged by means of signboard and posters.	95	73	85	70	95	80	60	75	100	85	85
7) FIRE PREVENTION/PROTECTION											
7.1 Adequate number and proper type of fire extinguishers are provided.	90	90	95	90	85	60	30	80	85	90	90
7.2 Fire extinguishers are easily accessible / free from obstacles.	70	95	95	90	80	70	30	70	65	80	80
7.3 Proper and permanent marking is provided for emergency escape routes and exits.	95	90	85	70	85	60	0	90	70	85	85
7.4 Uninterrupted and adequate lighting system is provided for emergency escape routes and exits.	95	80	85	70	95	20	0	95	50	75	75
7.5 Emergency escape routes are cleared from obstacles and made easy to quit.	60	100	90	95	95	35	20	70	10	50	50

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	Evaluation of variables (scale: 0-100) 0: Conformity is minimum 100: Conformity is maximum NA: If not applicable.										
	CS1	CS2	CS3	CS4	CS5	CS6	CS7	CS8	CS9	CS 10	CS 11
7.6 Emergency plan, procedures, assembly points and emergency telephone numbers are displayed at visible positions.	90	95	100	100	80	100	10	80	60	85	85
7.7 Adequate/proper number and quality of fire detectors are present.	60	0	20	50	75	50	0	90	60	80	80
7.8 Proper alarm system is present and clearly audible at all points on the site.	70	10	20	60	80	40	0	85	50	90	90
7.9 Firefighting equipment, detectors and alarm systems are regularly inspected and maintained.	75	55	86	70	70	50	0	90	60	75	75
7.10 Fire drills are conducted at regular intervals.	90	90	100	80	50	60	0	75	90	100	100
8) HAND/POWER TOOLS, MACHINERY AND DEVICES											
8.1 Hand/power tools, machinery and devices are used properly and not used for purposes other than it is intended.	70	90	95	80	90	75	60	70	90	90	90
8.2 Hand/power tools, machinery and devices are used or operated with security protection inserted.	80	85	80	95	80	70	50	80	75	80	80
8.3 Hand/power tools, machinery and devices are used with fixing and making sure of the soundness of the floor.	75	50	75	65	95	80	40	80	85	80	80
8.4 Hand/power tools, machinery and devices are not used or operated in damaged condition.	85	90	95	45	70	60	60	50	70	75	75
8.5 Hand/power tools, machinery and devices are used or operated by trained and authorized operators.	70	80	95	80	95	75	50	55	90	80	80
8.6 A trained pointer is present to guide operator in necessary situations.	60	90	90	60	100	90	60	70	50	25	25

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	**Evaluation of variables (scale: 0-100)** **0**: Conformity is minimum **100**: Conformity is maximum **NA**: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
8.7 Hand/power tools, machinery and devices are inspected and maintained daily.	75	100	85	80	65	75	60	75	40	55	55
8.8 Safe work instructions are provided to workers.	85	75	80	30	30	65	70	75	80	60	60
8.9 Hand/power tools, machinery and devices are clean enough.	80	55	85	80	90	50	50	60	50	80	80
8.10 Barricades and warning signs are placed when not in use.	70	0	50	0	0	60	60	10	50	25	25
8.11 Hand/power tools, machinery and devices are positioned in safe distances (E.g.: people, materials, tools, excavation, slope, underground facility, soft ground, obstacles, electricity lines)	65	95	80	60	85	65	60	30	70	45	45
8.12 Proper personal protective equipment (PPE) are used.	75	95	90	70	90	80	60	60	70	75	75
9) MATERIAL HANDLING (LOADING, TRANSPORT, UNLOADING, HANDLING AND STORAGE)											
9.1 Proper planning is made.	75	60	90	70	90	70	70	50	60	90	90
9.2 Transportation is supplied by proper vehicles.	80	90	85	60	80	75	50	60	75	70	70
9.3 Safe loading limitations are complied.	85	85	90	75	70	65	60	50	70	75	75
9.4 Loading/unloading/stacking is made by safe vehicles.	80	95	90	75	75	50	60	50	65	80	80
9.5 Loading places and ramps are designed according to dimensions of the load to be moved.	70	95	85	50	75	45	20	75	40	50	50
9.6 Forwarding lines that guide loads are used.	75	90	90	40	70	50	30	40	60	80	80

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	**Evaluation of variables (scale: 0-100)** **0**: Conformity is minimum **100**: Conformity is maximum **NA**: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
9.7 Removal/disposal of hazardous materials and chemicals is performed by specially trained personnel.	90	80	90	80	60	75	0	80	70	75	75
9.8 Storage of hazardous materials and chemicals does not exceed the allowed/exempted amount.	90	90	85	75	60	60	0	55	50	80	80
9.9 Legible warning labels are present on hazardous materials and chemicals.	95	55	100	90	100	70	0	80	80	100	100
9.10 Material safety data sheet (MSDS) are present for hazardous materials and chemicals.	95	100	100	90	100	90	0	90	85	95	95
9.11 Chemical hazard communication plan is clearly displayed at visible positions.	100	75	95	80	100	90	0	50	60	75	75
9.12 Proper personal protective equipment (PPE) are used.	90	95	75	80	80	70	30	60	70	80	80
10) TRAFFIC AND TRANSPORTATION CONTROL											
10.1 Vehicles are regularly inspected and maintained correctly.	80	80	90	90	60	80	65	50	75	95	95
10.2 Safety belts are used.	85	80	85	10	50	80	60	50	80	80	80
10.3 Drivers have appropriate license.	95	100	75	100	100	60	90	100	90	95	95
10.4 Drivers are trained / have experience.	80	85	86	80	80	70	70	40	75	60	60
10.5 Proper and adequate first aid kit/fire extinguisher tube is present in vehicles.	90	65	80	95	100	75	50	25	65	50	50
10.6 Routes are clear.	85	95	90	80	90	50	50	50	75	60	60
10.7 Roads have adequate width.	95	70	100	85	85	65	70	60	85	65	65

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	Evaluation of variables (scale: 0-100) 0: Conformity is minimum 100: Conformity is maximum NA: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
10.8 Adequate distance between roads (having vehicle traffic) and doors, gates, pedestrian passageways, corridors and stairs is kept.	85	100	100	80	70	90	60	50	70	60	60
10.9 Adequate number of direction and warning signs are present.	88	85	90	80	80	85	40	50	80	65	65
10.10 Drivers comply with speed limits.	50	0	40	50	95	70	60	40	70	75	75
10.11 Preventive measures are taken against excavation material spillage and dust.	70	95	80	0	0	50	0	30	80	50	50
10.12 Preventive measures are taken against the entry of unauthorized people to prohibited areas.	65	50	60	50	90	60	30	70	90	75	75
11) FIRST AID											
11.1 Trained first aid staff is present at site.	90	70	90	95	95	60	0	90	80	100	100
11.2 First aid staff and their contact information are displayed at visible positions.	95	100	95	90	90	75	0	75	85	90	90
11.3 Adequate number of first aid supplies and equipment are present.	90	70	80	95	95	90	50	50	80	85	85
11.4 First aid supplies and equipment can be accessed easily.	80	90	80	75	100	50	50	60	70	75	75
11.5 First aid supplies and equipment are ready for use.	90	70	90	90	95	60	50	50	75	85	85
11.6 First aid supplies and equipment are marked appropriately.	95	100	100	65	95	60	50	70	75	85	85

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	Evaluation of variables (scale: 0-100) **0**: Conformity is minimum **100**: Conformity is maximum **NA**: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
11.7 Adequate number of emergency treatment rooms are present.	70	75	80	100	100	50	20	30	50	90	90
11.8 On-site doctor is present at site.	95	100	90	50	100	80	20	90	75	80	80
12) EXCAVATION WORKS											
12.1 Inspection and control of excavation works is performed by authorized people.	85	100	95	70	95	60	60	50	75	85	85
12.2 Underground facilities in excavation areas are located by using detectors, etc. (E.g.: cable, gas, water, sewer lines) before excavation.	80	85	80	80	85	60	70	50	70	90	90
12.3 Proper barriers, railings and warning signs are placed.	90	70	95	95	90	50	40	60	85	80	80
12.4 Night work is performed with providing adequate lighting.	95	95	95	50	95	60	50	30	70	50	50
12.5 Safe entry and exit gates are used to access working area.	85	75	90	75	90	50	50	65	75	70	70
12.6 Secured stop blocks are placed to prevent the vehicles from falling into excavation area.	70	85	80	40	60	20	0	30	50	65	65
12.7 Materials are placed in a safe distance from the excavation edges.	80	75	95	60	95	65	50	60	75	80	80
12.8 Excavation is supported properly and adequately by performing static calculations of the excavation area (with slab, timber, trench boxes, shoring, lining, etc.).	75	0	50	70	0	30	50	65	80	75	75
12.9 Excavation area is sloped with proper angles.	85	90	95	85	60	40	20	40	80	70	70
12.10 Excavation works are avoided while raining.	90	80	90	50	95	50	80	70	50	80	80

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	**Evaluation of variables (scale: 0-100)** **0**: Conformity is minimum **100**: Conformity is maximum **NA**: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
12.11 Entry of unauthorized people to the excavation area is prevented.	75	90	95	50	90	60	80	70	90	75	75
12.12 Proper personal protective equipment (PPE) are used.	80	60	90	75	90	80	70	70	85	95	95
13) CONCRETE AND FORMWORK											
13.1 Concrete and form works are performed under the supervision of a competent person.	95	60	90	75	100	50	30	55	75	80	80
13.2 Design and installation works of form panels, supports and struts are performed with respect to the exposed loads on it.	85	85	85	65	90	70	40	50	70	75	75
13.3 Strong and non-deformed forms are used.	80	65	85	80	95	50	40	70	85	90	90
13.4 Grounded electrical vibrators are used.	80	70	75	95	95	90	60	60	80	80	80
13.5 Exposure of reinforcing bars is preserved.	75	75	90	60	95	50	60	50	75	100	100
13.6 Concrete pump is positioned properly to the ground that concrete will be poured.	85	90	90	95	95	60	60	75	80	90	90
13.7 Concrete pump's supporting foots are properly fixed to the ground.	90	80	95	70	100	75	60	80	75	80	80
13.8 Surrounding facilities are taken account while opening and closing pump handles.	95	90	100	85	100	75	70	75	80	85	85
13.9 Necessary precautions are taken while pump is operated under energy transmission lines.	90	70	100	60	100	75	50	50	75	60	60
13.10 Work is not allowed and performed directly below the concrete pouring area	100	80	80	50	95	75	60	60	70	85	85

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	Evaluation of variables (scale: 0-100) **0**: Conformity is minimum **100**: Conformity is maximum **NA**: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
13.11 Proper personal protective equipment (PPE) are used.	90	65	85	80	90	70	70	60	75	90	90
14) WELDING WORKS											
14.1 Welding equipments are daily inspected/controlled and maintained.	95	60	90	85	65	60	50	75	95	80	80
14.2 Adequate ventilation is supplied to narrow and confined areas.	90	80	95	80	70	50	30	60	95	80	80
14.3 Gas cylinders are kept upright and fastened in order not to overturn when shaked.	100	70	95	50	90	70	0	70	75	50	50
14.4 Proper type of fire extinguishers are nearby.	85	80	80	75	60	30	30	50	70	60	60
14.5 Adequate separation distance is put between fuels and oxygen.	70	90	75	50	40	40	10	30	90	65	65
14.6 Oxygen tube is not contacted with oily hand.	90	90	95	100	95	50	0	50	100	75	75
14.7 Necessary precautions are taken against electrical and gas leakage.	80	95	75	75	95	30	0	60	80	70	70
14.8 Non-deformed hoses are used.	75	75	80	70	95	60	70	50	65	50	50
14.9 Welders have license/certificate.	100	100	90	95	100	85	80	95	100	90	90
14.10 Proper personal protective equipment (PPE) are used.	95	90	95	95	90	75	60	80	90	85	85
15) DEMOLITION WORKS											
15.1 Preparation and planning of actions is performed before the start of demolition works.	85	NA	NA	NA	NA	50	0	75	95	100	100
15.2 Demolition area is enclosed and warning signs are placed.	90	NA	NA	NA	NA	40	10	70	100	90	90

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	Evaluation of variables (scale: 0-100) **0**: Conformity is minimum **100**: Conformity is maximum **NA**: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
15.3 Existing service lines (gas, water, electricity lines, etc.) are taken under control or cut where necessary.	95	NA	NA	NA	NA	65	30	70	90	70	70
15.4 Demolition works are performed under the supervision of competent person.	90	NA	NA	NA	NA	60	20	75	85	80	80
15.5 People, vehicles, materials and equipment are removed enough from the demolition area.	95	NA	NA	NA	NA	70	30	50	70	90	90
15.6 Necessary precautions are taken to avoid dust during demolition.	100	NA	NA	NA	NA	0	0	60	65	80	80
15.7 Materials and ruins are transported in a systematical and secured way.	85	NA	NA	NA	NA	50	0	30	80	50	50
15.8 Asbestos powder measurement is performed for structures that may contain asbestos.	90	NA	NA	NA	NA	0	0	25	50	70	70
15.9 Proper personal protective equipment (PPE) are used.	90	NA	NA	NA	NA	60	15	70	85	85	85
16) WORKERS											
16.1 Workers do not avoid the use of personal protective equipment intentionally.	80	45	50	60	20	60	70	60	75	90	90
16.2 Workers do not take the apparent risks.	50	80	100	90	70	40	30	60	60	75	75
16.3 Workers perform correct methods and applications.	75	70	80	50	60	55	70	50	80	80	80
16.4 Workers perform their job with plan and cautiousness.	80	65	80	75	50	55	70	60	80	85	85
16.5 Workers have safety consciousness.	75	70	75	75	70	60	30	70	75	85	85
16.6 Workers perform their job with morale.	80	90	90	55	30	15	70	40	90	80	80

Table G.1: The filled forms for case studies (Cont'd)

VARIABLES AFFECTING SAFETY PERFORMANCE	Evaluation of variables (scale: 0-100) **0**: Conformity is minimum **100**: Conformity is maximum **NA**: If not applicable.										
	CS1	**CS2**	**CS3**	**CS4**	**CS5**	**CS6**	**CS7**	**CS8**	**CS9**	**CS 10**	**CS 11**
16.7 Workers do not perform their jobs without permission.	90	80	95	90	95	50	40	50	70	60	60
16.8 Workers do not use alcohol or drug.	95	85	85	90	100	50	10	50	90	95	95
16.9 Workers do not change continuously (Personnel turnover rate is low.).	75	70	85	70	65	30	20	50	70	75	75
16.10 Adequate safety trainings are supplied to workers.	95	75	95	80	90	50	60	80	100	90	90

APPENDIX H

THE CALCULATION OF THE SITE SAFETY PERFORMANCE INDEX OF CASE STUDY #1 BY FULL MODEL

The calculation of the site safety performance index of case study #1 by full model is presented on the following pages.

Table H.1: The calculation of the site safety performance index of case study #1 by full model

	FLj	WOj = FLj / Σ (FLj)	UWOj = [1 / Σ (WOj)] * WOj	SEj	WMDi = Σ(UWOj * SEj)		SPCDi	WDi = (SPCDi) / Σ (SPCDi)	UWDi = [1 / Σ (WDi)] * WDi]	SPI = Σ(UWOj * SEj * UWDi)
Observed Variable j	**Factor loading of the observed variable j**	**Relative weight of the observed variable j**	**Updated relative weight of the observed variable j**	**Site evaluation of the observed variable j (scale: 0-100)**	**The weighted mean of the site observations of each dimension**	**Dimension i**	**Standardized path coefficient of dimension i**	**Relative weight of dimension i**	**Updated relative weight of dimension i**	**Safety Performance Index of Construction Site**
G1F5	0,71	0,0911	0,0911	90	8,2028	**G1**	0,7900	0,0568	0,0568	0,4659
G1F1	0,70	0,0899	0,0899	100	8,9859					0,5103
G1F3	0,69	0,0886	0,0886	90	7,9718					0,4527
G1F11	0,68	0,0873	0,0873	95	8,2927					0,4710
G1F2	0,66	0,0847	0,0847	87	7,3710					0,4186
G1F6	0,66	0,0847	0,0847	75	6,3543					0,3609
G1F8	0,65	0,0834	0,0834	60	5,0064					0,2843
G1F7	0,64	0,0822	0,0822	50	4,1078					0,2333
G1F9	0,64	0,0822	0,0822	50	4,1078					0,2333
G1F12	0,61	0,0783	0,0783	80	6,2644					0,3558
G1F4	0,58	0,0745	0,0745	75	5,5841					0,3171
G1F10	0,57	0,0732	0,0732	85	6,2195					0,3532
SUM	**7,79**	**1,00**	**1,00**		**78,47**					**4,4565**
G2F7	0,80	0,1153	0,1153	85	9,7983	**G2**	0,8300	0,0597	0,0597	0,5847
G2F6	0,78	0,1124	0,1124	75	8,4294					0,5030
G2F2	0,75	0,1081	0,1081	90	9,7262					0,5804
G2F3	0,71	0,1023	0,1023	75	7,6729					0,4578
G2F5	0,70	0,1009	0,1009	50	5,0432					0,3009
G2F1	0,67	0,0965	0,0965	80	7,7233					0,4608
G2F4	0,67	0,0965	0,0965	85	8,2061					0,4896
G2F9	0,67	0,0965	0,0965	70	6,7579					0,4032
G2F8	0,63	0,0908	0,0908	70	6,3545					0,3792
G2F10	0,56	0,0807	0,0807	60	4,8415					0,2889
SUM	**6,94**	**1,00**	**1,00**		**74,55**					**4,4485**

Table H.1: The calculation of the site safety performance index of case study #1 by full model (Cont'd)

G6F8	0,84	0,1195	0,1195	85	10,1565					0,6206
G6F5	0,82	0,1166	0,1166	85	9,9147					0,6059
G6F1	0,81	0,1152	0,1152	90	10,3698					0,6337
G6F7	0,80	0,1138	0,1138	80	9,1038					0,5563
G6F2	0,78	0,1110	0,1110	80	8,8762	**G6**	0,8500	0,0611	0,0611	0,5424
G6F3	0,78	0,1110	0,1110	90	9,9858					0,6102
G6F4	0,76	0,1081	0,1081	75	8,1081					0,4955
G6F6	0,73	0,1038	0,1038	90	9,3457					0,5711
G6F9	0,71	0,1010	0,1010	95	9,5946					0,5863
SUM	**7,03**	**1,00**	**1,00**		**85,46**					**5,2219**
G7F4	0,84	0,1094	0,1094	95	10,3906					0,6200
G7F6	0,83	0,1081	0,1081	90	9,7266					0,5804
G7F8	0,83	0,1081	0,1081	70	7,5651					0,4514
G7F9	0,81	0,1055	0,1055	75	7,9102					0,4720
G7F3	0,78	0,1016	0,1016	95	9,6484	**G7**	0,8300	0,0597	0,0597	0,5757
G7F5	0,77	0,1003	0,1003	60	6,0156					0,3589
G7F7	0,77	0,1003	0,1003	60	6,0156					0,3589
G7F2	0,70	0,0911	0,0911	70	6,3802					0,3807
G7F1	0,68	0,0885	0,0885	90	7,9688					0,4755
G7F10	0,67	0,0872	0,0872	90	7,8516					0,4685
SUM	**7,68**	**1,00**	**1,00**		**79,47**					**4,7421**
G8F4	0,82	0,0882	0,0882	85	7,4946					0,4849
G8F2	0,79	0,0849	0,0849	80	6,7957					0,4397
G8F8	0,79	0,0849	0,0849	85	7,2204					0,4672
G8F11	0,79	0,0849	0,0849	65	5,5215					0,3573
G8F5	0,78	0,0839	0,0839	70	5,8710					0,3799
G8F7	0,78	0,0839	0,0839	75	6,2903	**G8**	0,9000	0,0647	0,0647	0,4070
G8F12	0,78	0,0839	0,0839	75	6,2903					0,4070
G8F9	0,77	0,0828	0,0828	80	6,6237					0,4286
G8F3	0,76	0,0817	0,0817	75	6,1290					0,3966
G8F6	0,76	0,0817	0,0817	60	4,9032					0,3172
G8F1	0,75	0,0806	0,0806	70	5,6452					0,3653
G8F10	0,73	0,0785	0,0785	70	5,4946					0,3555
SUM	**9,30**	**1,00**	**1,00**		**74,28**					**4,8060**

Table H.1: The calculation of the site safety performance index of case study #1 by full model (Cont'd)

G9F9	0,81	0,0875	0,0875	95	8,3099	G9	0,9400	0,0676	0,0676	0,5616
G9F6	0,80	0,0864	0,0864	75	6,4795					0,4379
G9F2	0,79	0,0853	0,0853	80	6,8251					0,4612
G9F3	0,79	0,0853	0,0853	85	7,2516					0,4900
G9F4	0,79	0,0853	0,0853	80	6,8251					0,4612
G9F10	0,79	0,0853	0,0853	95	8,1048					0,5477
G9F5	0,77	0,0832	0,0832	70	5,8207					0,3933
G9F8	0,76	0,0821	0,0821	90	7,3866					0,4992
G9F7	0,75	0,0810	0,0810	90	7,2894					0,4926
G9F11	0,75	0,0810	0,0810	100	8,0994					0,5473
G9F12	0,74	0,0799	0,0799	90	7,1922					0,4860
G9F1	0,72	0,0778	0,0778	75	5,8315					0,3941
SUM	**9,26**	**1,00**	**1,00**		**85,42**					**5,7722**
G10F7	0,82	0,0975	0,0975	95	9,2628	G10	0,9400	0,0676	0,0676	0,6260
G10F9	0,81	0,0963	0,0963	88	8,4756					0,5728
G10F8	0,79	0,0939	0,0939	85	7,9845					0,5396
G10F12	0,77	0,0916	0,0916	65	5,9512					0,4022
G10F1	0,76	0,0904	0,0904	80	7,2295					0,4885
G10F11	0,73	0,0868	0,0868	70	6,0761					0,4106
G10F6	0,68	0,0809	0,0809	85	6,8728					0,4644
G10F3	0,65	0,0773	0,0773	95	7,3424					0,4962
G10F4	0,65	0,0773	0,0773	80	6,1831					0,4178
G10F5	0,63	0,0749	0,0749	90	6,7420					0,4556
G10F2	0,57	0,0678	0,0678	85	5,7610					0,3893
G10F10	0,55	0,0654	0,0654	50	3,2699					0,2210
SUM	**8,41**	**1,00**	**1,00**		**81,15**					**5,4840**
G11F4	0,95	0,1418	0,1418	80	11,3433	G11	0,6500	0,0467	0,0467	0,5301
G11F3	0,93	0,1388	0,1388	90	12,4925					0,5838
G11F5	0,91	0,1358	0,1358	90	12,2239					0,5712
G11F6	0,86	0,1284	0,1284	95	12,1940					0,5698
G11F2	0,81	0,1209	0,1209	95	11,4851					0,5367
G11F7	0,80	0,1194	0,1194	70	8,3582					0,3906
G11F1	0,79	0,1179	0,1179	90	10,6119					0,4959
G11F8	0,65	0,0970	0,0970	95	9,2164					0,4307
SUM	**6,70**	**1,00**	**1,00**		**87,93**					**4,1087**

Table H.1: The calculation of the site safety performance index of case study #1 by full model (Cont'd)

G12F5	0,84	0,0936	0,0936	85	7,9599					0,5322
G12F1	0,83	0,0925	0,0925	85	7,8651					0,5258
G12F4	0,80	0,0892	0,0892	95	8,4727					0,5665
G12F7	0,78	0,0870	0,0870	80	6,9565					0,4651
G12F11	0,78	0,0870	0,0870	75	6,5217					0,4360
G12F3	0,76	0,0847	0,0847	90	7,6254	**G12**	0,9300	0,0669	0,0669	0,5098
G12F12	0,75	0,0836	0,0836	80	6,6890					0,4472
G12F9	0,74	0,0825	0,0825	85	7,0123					0,4688
G12F6	0,73	0,0814	0,0814	70	5,6968					0,3809
G12F2	0,69	0,0769	0,0769	80	6,1538					0,4114
G12F10	0,64	0,0713	0,0713	90	6,4214					0,4293
G12F8	0,63	0,0702	0,0702	75	5,2676					0,3522
SUM	**8,97**	**1,00**	**1,00**		**82,64**					**5,5253**
G13F7	0,83	0,0960	0,0960	90	8,6358					0,5463
G13F3	0,82	0,0948	0,0948	80	7,5838					0,4798
G13F10	0,82	0,0948	0,0948	100	9,4798					0,5997
G13F8	0,81	0,0936	0,0936	95	8,8960					0,5628
G13F1	0,79	0,0913	0,0913	95	8,6763					0,5489
G13F2	0,79	0,0913	0,0913	85	7,7630	**G13**	0,8800	0,0633	0,0633	0,4911
G13F4	0,79	0,0913	0,0913	80	7,3064					0,4622
G13F9	0,79	0,0913	0,0913	90	8,2197					0,5200
G13F6	0,77	0,0890	0,0890	85	7,5665					0,4787
G13F11	0,77	0,0890	0,0890	90	8,0116					0,5068
G13F5	0,67	0,0775	0,0775	75	5,8092					0,3675
SUM	**8,65**	**1,00**	**1,00**		**87,95**					**5,5639**
G14F9	0,85	0,1117	0,1117	100	11,1695					0,7548
G14F2	0,80	0,1051	0,1051	90	9,4612					0,6394
G14F1	0,79	0,1038	0,1038	95	9,8620					0,6664
G14F10	0,79	0,1038	0,1038	95	9,8620					0,6664
G14F7	0,77	0,1012	0,1012	80	8,0946	**G14**	0,9400	0,0676	0,0676	0,5470
G14F8	0,76	0,0999	0,0999	75	7,4901					0,5062
G14F5	0,75	0,0986	0,0986	70	6,8988					0,4662
G14F3	0,74	0,0972	0,0972	100	9,7240					0,6571
G14F4	0,70	0,0920	0,0920	85	7,8187					0,5284
G14F6	0,66	0,0867	0,0867	90	7,8055					0,5275
SUM	**7,61**	**1,00**	**1,00**		**88,19**					**5,9594**

Table H.1: The calculation of the site safety performance index of case study #1 by full model (Cont'd)

G15F2	0,81	0,1274	0,1274	90	11,4623					0,7663
G15F4	0,78	0,1226	0,1226	90	11,0377					0,7380
G15F9	0,74	0,1164	0,1164	90	10,4717					0,7001
G15F1	0,73	0,1148	0,1148	85	9,7563					0,6523
G15F5	0,72	0,1132	0,1132	95	10,7547	**G15**	0,9300	0,0669	0,0669	0,7190
G15F3	0,71	0,1116	0,1116	95	10,6053					0,7091
G15F7	0,65	0,1022	0,1022	85	8,6871					0,5808
G15F8	0,62	0,0975	0,0975	90	8,7736					0,5866
G15F6	0,60	0,0943	0,0943	100	9,4340					0,6307
SUM	**6,36**	**1,00**	**1,00**		**90,98**					**6,0830**
G16F3	0,80	0,1111	0,1111	75	8,3333					0,5152
G16F2	0,79	0,1097	0,1097	50	5,4861					0,3392
G16F5	0,79	0,1097	0,1097	75	8,2292					0,5088
G16F4	0,76	0,1056	0,1056	80	8,4444					0,5221
G16F7	0,76	0,1056	0,1056	90	9,5000	**G16**	0,8600	0,0618	0,0618	0,5873
G16F10	0,74	0,1028	0,1028	95	9,7639					0,6037
G16F1	0,70	0,0972	0,0972	80	7,7778					0,4809
G16F6	0,65	0,0903	0,0903	80	7,2222					0,4465
G16F9	0,61	0,0847	0,0847	75	6,3542					0,3929
G16F8	0,60	0,0833	0,0833	95	7,9167					0,4895
SUM	**7,20**	**1,00**	**1,00**		**79,03**					**4,8860**
							13,9100	**1,0000**	**1,0000**	
					Site Safety Performance Index of Case Study #1					**82,1587**

APPENDIX I

THE CALCULATION OF THE SITE SAFETY PERFORMANCE INDEX OF CASE STUDY #1 BY SHORT MODEL

The calculation of the site safety performance index of case study #1 by short model is presented on the following pages.

Table I.1: The calculation of the site safety performance index of case study #1 by short model

	FLj	WOj = FLj / Σ (FLj)	UWOj = [1 / Σ (WOj)] * WOj	SEj	WMDi = Σ(UWOj * SEj)		SPCDi	WDi = (SPCDi) / Σ (SPCDi)	UWDi = [1 / Σ (WDi)] * WDi	SPI = Σ(UWOj * SEj * UWDi)
Observed Variable j	**Factor loading of the observed variable j**	**Relative weight of the observed variable j**	**Updated relative weight of the observed variable j**	**Site evaluation of the observed variable j (scale: 0-100)**	**The weighted mean of the site observations of each dimension**	**Dimension i**	**Standardized path coefficient of dimension i**	**Relative weight of dimension i**	**Updated relative weight of dimension i**	**Safety Performance Index of Construction Site**
G1F5	0,71	0,3381	0,3381	90	30,4286					1,7282
G1F1	0,70	0,3333	0,3333	100	33,3333	**G1**	0,7900	0,0568	0,0568	1,8931
G1F3	0,69	0,3286	0,3286	90	29,5714					1,6795
SUM	**2,10**	**1,00**	**1,00**		**93,33**					**5,3007**
G2F7	0,80	0,3433	0,3433	85	29,1845					1,7414
G2F6	0,78	0,3348	0,3348	75	25,1073	**G2**	0,8300	0,0597	0,0597	1,4981
G2F2	0,75	0,3219	0,3219	90	28,9700					1,7286
SUM	**2,33**	**1,00**	**1,00**		**83,26**					**4,9682**
G3F4	0,76	0,3408	0,3408	75	25,5605					1,6171
G3F8	0,74	0,3318	0,3318	50	16,5919	**G3**	0,8800	0,0633	0,0633	1,0497
G3F9	0,73	0,3274	0,3274	70	22,9148					1,4497
SUM	**2,23**	**1,00**	**1,00**		**65,07**					**4,1164**
G4F5	0,79	0,3465	0,3465	85	29,4518					1,9268
G4F8	0,75	0,3289	0,3289	80	26,3158	**G4**	0,9100	0,0654	0,0654	1,7216
G4F9	0,74	0,3246	0,3246	90	29,2105					1,9110
SUM	**2,28**	**1,00**	**1,00**		**84,98**					**5,5593**
G5F8	0,80	0,3463	0,3463	90	31,1688					1,9046
G5F11	0,76	0,3290	0,3290	85	27,9654	**G5**	0,8500	0,0611	0,0611	1,7089
G5F4	0,75	0,3247	0,3247	60	19,4805					1,1904
SUM	**2,31**	**1,00**	**1,00**		**78,61**					**4,8039**

Table I.1: The calculation of the site safety performance index of case study #1 by short model (Cont'd)

G6F8	0,84	0,3401	0,3401	85	28,9069					1,7664
G6F5	0,82	0,3320	0,3320	85	28,2186	**G6**	0,8500	0,0611	0,0611	1,7244
G6F1	0,81	0,3279	0,3279	90	29,5142					1,8035
SUM	**2,47**	**1,00**	**1,00**		**86,64**					**5,2943**
G7F4	0,84	0,3360	0,3360	95	31,9200					1,9046
G7F6	0,83	0,3320	0,3320	90	29,8800	**G7**	0,8300	0,0597	0,0597	1,7829
G7F8	0,83	0,3320	0,3320	70	23,2400					1,3867
SUM	**2,50**	**1,00**	**1,00**		**85,04**					**5,0743**
G8F4	0,82	0,3417	0,3417	85	29,0417					1,8790
G8F2	0,79	0,3292	0,3292	80	26,3333	**G8**	0,9000	0,0647	0,0647	1,7038
G8F8	0,79	0,3292	0,3292	85	27,9792					1,8103
SUM	**2,40**	**1,00**	**1,00**		**83,35**					**5,3932**
G9F9	0,81	0,3375	0,3375	95	32,0625					2,1667
G9F6	0,80	0,3333	0,3333	75	25,0000	**G9**	0,9400	0,0676	0,0676	1,6894
G9F2	0,79	0,3292	0,3292	80	26,3333					1,7795
SUM	**2,40**	**1,00**	**1,00**		**83,40**					**5,6357**
G10F7	0,82	0,3388	0,3388	95	32,1901					2,1753
G10F9	0,81	0,3347	0,3347	88	29,4545	**G10**	0,9400	0,0676	0,0676	1,9905
G10F8	0,79	0,3264	0,3264	85	27,7479					1,8751
SUM	**2,42**	**1,00**	**1,00**		**89,39**					**6,0409**
G11F4	0,95	0,3405	0,3405	80	27,2401					1,2729
G11F3	0,93	0,3333	0,3333	90	30,0000	**G11**	0,6500	0,0467	0,0467	1,4019
G11F5	0,91	0,3262	0,3262	90	29,3548					1,3717
SUM	**2,79**	**1,00**	**1,00**		**86,59**					**4,0465**

Table I.1: The calculation of the site safety performance index of case study #1 by short model (Cont'd)

G12F5	0,84	0,3401	0,3401	85	28,9069	G12	0,9300	0,0669	0,0669	1,9327
G12F1	0,83	0,3360	0,3360	85	28,5628					1,9097
G12F4	0,80	0,3239	0,3239	95	30,7692					2,0572
SUM	**2,47**	**1,00**	**1,00**		**88,24**					**5,8995**
G13F7	0,83	0,3360	0,3360	90	30,2429	G13	0,8800	0,0633	0,0633	1,9133
G13F3	0,82	0,3320	0,3320	80	26,5587					1,6802
G13F10	0,82	0,3320	0,3320	100	33,1984					2,1003
SUM	**2,47**	**1,00**	**1,00**		**90,00**					**5,6937**
G14F9	0,85	0,3484	0,3484	100	34,8361	G14	0,9400	0,0676	0,0676	2,3541
G14F2	0,80	0,3279	0,3279	90	29,5082					1,9941
G14F1	0,79	0,3238	0,3238	95	30,7582					2,0786
SUM	**2,44**	**1,00**	**1,00**		**95,10**					**6,4268**
G15F2	0,81	0,3476	0,3476	90	31,2876	G15	0,9300	0,0669	0,0669	2,0918
G15F4	0,78	0,3348	0,3348	90	30,1288					2,0144
G15F9	0,74	0,3176	0,3176	90	28,5837					1,9111
SUM	**2,33**	**1,00**	**1,00**		**90,00**					**6,0173**
G16F3	0,80	0,3361	0,3361	75	25,2101	G16	0,8600	0,0618	0,0618	1,5586
G16F2	0,79	0,3319	0,3319	50	16,5966					1,0261
G16F5	0,79	0,3319	0,3319	75	24,8950					1,5392
SUM	**2,38**	**1,00**	**1,00**		**66,70**					**4,1239**
							13,9100	**1,0000**	**1,0000**	
					Site Safety Performance Index of Case Study #1					**84,3945**

APPENDIX J

RECOMMENDATIONS TO CONSTRUCTION SAFETY PROFESSIONALS (FULL LIST)

Table J.1: Recommendations to construction safety professionals (full list)

1) SCAFFOLDINGS AND WORKING PLATFORMS
1.1 Installation, operation and disassembly plan for the scaffolding should be present.
1.2 Defective and worn fasteners should not be used in scaffolding system.
1.3 Fastening and supporting against horizontal and vertical forces should be performed properly.
1.4 Rubbish and waste material on scaffoldings and platforms should be cleared not to block people to pass.
1.5 Guard rails, intermediate rails, toe boards, screens and plankings should comply with the standards.
1.6 Gateways with proper system should be present at scaffoldings.
1.7 Preventive measures (barrier/warning notices) should be taken for incomplete/unsafe scaffolds.
1.8 Scaffolding and working platforms should be controlled/inspected before use.
1.9 Sign boards should be hung indicating the maximum load capacity that scaffoldings can bear at proper and visible places.
1.10 Scaffoldings and working platforms should not be overloaded.
1.11 Assembly and disassembly operations should be performed by experienced/trained people.
1.12 Proper personal protective equipment (PPE) should be used.
2) LADDERS AND STAIRS
2.1 Ladders and stairs should be made up of strong and non-defective material.
2.2 Equipment with undamaged rungs, arms or connection parts should be used in ladders/stairs.
2.3 Ladders/stairs should be based on firm and leveled foundation.
2.4 Ladders' bottom and top parts should be fixed properly.
2.5 Ladders/stairs with missing parts should be tagged.
2.6 Proper ladders should be used for the job.
2.7 Ladders should be positioned at the correct angle.

Table J.1: Recommendations to construction safety professionals (full list) (Cont'd)

2.8	Ladders/stairs should be in clean condition.
2.9	Ladders/stairs should be positioned in a safe distance from vehicles, mobile cranes and electricity lines etc.
2.10	Ladders/stairs should be inspected daily and maintained.
3)	**WORKING AT HEIGHT AND PROTECTION AGAINST FALLING**
3.1	Working at height should be planned in advance and required organizations should be made.
3.2	Barriers and warning signs should be placed for open edges and holes.
3.3	Safety nets and air bags should comply with the standards.
3.4	Guardrails, handrails or rails should comply with the standards.
3.5	Employee's access to working places by inconvenient means and equipment should be restricted.
3.6	Preventive measures against falling of hand tools and other materials should be taken.
3.7	Access to the areas subject to falling objects should be prevented and gateways with coverings should be erected.
3.8	Safe working equipment used at heights should be regularly inspected and maintained.
3.9	Proper personal protective equipment (PPE) should be used.
4)	**LIGHTING AND ELECTRICITY**
4.1	Adequate illumination should be supplied to working places, passageways and routes.
4.2	Auxiliary illumination system should be present against electricity cuts.
4.3	Proper connectors should be used (E.g.: connections with close-ended cables)
4.4	Proper residual current devices should be used in the main and secondary electricity panels.
4.5	Panels, boards, control apparatus, etc. should be stored in lockers or cabinets
4.6	Cabinets, panels and switches located in wet locations should be enclosed with weather-proof enclosures.
4.7	Overhead lines should be marked and appropriate measures should be taken to prevent contact with them.
4.8	All of the hardware and connection works should be done by authorized people.
4.9	Electrical danger posts and warning signs should be present.
4.10	Proper personal protective equipment (PPE) should be used.
5)	**HOUSEKEEPING, ORDER AND TIDINESS**
5.1	Sufficient space should be present for working areas.
5.2	Appropriate places should be provided where employees can relax.
5.3	Garbage should be collected regularly and dumped carefully.

Table J.1: Recommendations to construction safety professionals (full list) (Cont'd)

5.4 Preventive measures (barriers/warning signs) should be taken for slippery surfaces.
5.5 Construction site should be fenced properly to prevent unauthorized entry.
5.6 Working areas should be cleared from waste and materials with sharp and keen edges (E.g.: form with nails).
5.7 Isolation tapes and warning notices should be provided for plant and equipment temporarily suspended for work execution.
5.8 The sanitary facilities should be adequate and comply with the hygiene requirements.
5.9 Sufficient amount of potable water should be provided.
5.10 Chemical and biological analyzes should be performed for potable water.
5.11 Measurement and control of harmful dusts, gases, fumes, vapors, vibration, noise, pollution should be performed.
5.12 Necessary measures should be taken for protection of workers from too hot and cold.
6) PERSONAL PROTECTIVE EQUIPMENT (PPE)
6.1 Personal protective equipments should have appropriate standards.
6.2 Workers should access personal protective equipments easily.
6.3 Adequate amounts of personal protective equipments should be provided.
6.4 Personal protective equipments should be used by workers correctly and properly.
6.5 Personal protective equipments should be inspected before each use.
6.6 Damaged personal protective equipments should not be used.
6.7 Adequate instruction and practical training should be provided to workers for use and maintenance.
6.8 Personal protective equipments should be maintained regularly and kept clean.
6.9 Use of personal protective equipment should be encouraged by means of signboard and posters.
7) FIRE PREVENTION/PROTECTION
7.1 Adequate number and proper type of fire extinguishers should be provided.
7.2 Fire extinguishers should be easily accessible / free from obstacles.
7.3 Proper and permanent marking should be provided for emergency escape routes and exits.
7.4 Uninterrupted and adequate lighting system should be provided for emergency escape routes and exits.
7.5 Emergency escape routes should be cleared from obstacles and made easy to quit.
7.6 Emergency plan, procedures, assembly points and emergency telephone numbers should be displayed at visible positions.
7.7 Adequate/proper number and quality of fire detectors should be present.

Table J.1: Recommendations to construction safety professionals (full list) (Cont'd)

7.8	Proper alarm system should be present and clearly audible at all points on the site.
7.9	Firefighting equipment, detectors and alarm systems should be regularly inspected and maintained.
7.10	Fire drills should be conducted at regular intervals.
8)	**HAND/POWER TOOLS, MACHINERY AND DEVICES**
8.1	Hand/power tools, machinery and devices should be used properly and not used for purposes other than it is intended.
8.2	Hand/power tools, machinery and devices should be used or operated with security protection inserted.
8.3	Hand/power tools, machinery and devices should be used with fixing and making sure of the soundness of the floor.
8.4	Hand/power tools, machinery and devices should not be used or operated in damaged condition.
8.5	Hand/power tools, machinery and devices should be used or operated by trained and authorized operators.
8.6	A trained pointer should be present to guide operator in necessary situations.
8.7	Hand/power tools, machinery and devices should be inspected and maintained daily.
8.8	Safe work instructions should be provided to workers.
8.9	Hand/power tools, machinery and devices should be clean enough.
8.10	Barricades and warning signs should be placed when not in use.
8.11	Hand/power tools, machinery and devices should be positioned in safe distances (E.g.: people, materials, tools, excavation, slope, underground facility, soft ground, obstacles, electricity lines)
8.12	Proper personal protective equipment (PPE) should be used.
9)	**MATERIAL HANDLING (LOADING, TRANSPORT, UNLOADING, HANDLING AND STORAGE)**
9.1	Proper planning should be made.
9.2	Transportation should be supplied by proper vehicles.
9.3	Safe loading limitations should be complied.
9.4	Loading/unloading/stacking should be made by safe vehicles.
9.5	Loading places and ramps should be designed according to dimensions of the load to be moved.
9.6	Forwarding lines that guide loads should be used.
9.7	Removal/disposal of hazardous materials and chemicals should be performed by specially trained personnel.
9.8	Storage of hazardous materials and chemicals should not exceed the allowed/exempted amount.

Table J.1: Recommendations to construction safety professionals (full list) (Cont'd)

9.9 Legible warning labels should be present on hazardous materials and chemicals.
9.10 Material safety data sheet (MSDS) should be present for hazardous materials and chemicals.
9.11 Chemical hazard communication plan should be clearly displayed at visible positions.
9.12 Proper personal protective equipment (PPE) should be used.
10) TRAFFIC AND TRANSPORTATION CONTROL
10.1 Vehicles should be regularly inspected and maintained correctly.
10.2 Safety belts should be used.
10.3 Drivers should possess appropriate license.
10.4 Drivers should be trained / have experience.
10.5 Proper and adequate first aid kit/fire extinguisher tube should be present in vehicles.
10.6 Routes should be clear.
10.7 Roads should have adequate width.
10.8 Adequate distance between roads (having vehicle traffic) and doors, gates, pedestrian passageways, corridors and stairs should be kept.
10.9 Adequate number of direction and warning signs should be present.
10.10 Drivers should comply with speed limits.
10.11 Preventive measures should be taken against excavation material spillage and dust.
10.12 Preventive measures should be taken against the entry of unauthorized people to prohibited areas.
11) FIRST AID
11.1 Trained first aid staff should be present at site.
11.2 First aid staff and their contact information should be displayed at visible positions.
11.3 Adequate number of first aid supplies and equipment should be present.
11.4 First aid supplies and equipment should be accessed easily.
11.5 First aid supplies and equipment should be ready for use.
11.6 First aid supplies and equipment should be marked appropriately.
11.7 Adequate number of emergency treatment rooms should be present.
11.8 On-site doctor should be present at site.
12) EXCAVATION WORKS
12.1 Inspection and control of excavation works should be performed by authorized people.
12.2 Underground facilities in excavation areas should be located by using detectors, etc. (E.g.: cable, gas, water, sewer lines) before excavation.
12.3 Proper barriers, railings and warning signs should be placed.
12.4 Night work should be performed with providing adequate lighting.

Table J.1: Recommendations to construction safety professionals (full list) (Cont'd)

12.5	Safe entry and exit gates should be used to access working area.
12.6	Secured stop blocks should be placed to prevent the vehicles from falling into excavation area.
12.7	Materials should be placed in a safe distance from the excavation edges.
12.8	Excavation should be supported properly and adequately by performing static calculations of the excavation area (with slab, timber, trench boxes, shoring, lining, etc.).
12.9	Excavation area should be sloped with proper angles.
12.10	Excavation works should be avoided while raining.
12.11	Entry of unauthorized people to the excavation area should be prevented.
12.12	Proper personal protective equipment (PPE) should be used.
13)	**CONCRETE AND FORMWORK**
13.1	Concrete and form works should be performed under the supervision of a competent person.
13.2	Design and installation works of form panels, supports and struts should be performed with respect to the exposed loads on it.
13.3	Strong and non-deformed forms should be used.
13.4	Grounded electrical vibrators should be used.
13.5	Exposure of reinforcing bars should be preserved.
13.6	Concrete pump should be positioned properly to the ground that concrete will be poured.
13.7	Concrete pump's supporting foots should be properly fixed to the ground.
13.8	Surrounding facilities should be taken account while opening and closing pump handles.
13.9	Necessary precautions should be taken while pump is operated under energy transmission lines.
13.10	Work should be not allowed and performed directly below the concrete pouring area
13.11	Proper personal protective equipment (PPE) should be used.
14)	**WELDING WORKS**
14.1	Welding equipments should be daily inspected/controlled and maintained.
14.2	Adequate ventilation should be supplied to narrow and confined areas.
14.3	Gas cylinders should be kept upright and fastened in order not to overturn when shaked.
14.4	Proper type of fire extinguishers should be nearby.
14.5	Adequate separation distance should be put between fuels and oxygen.
14.6	Oxygen tube should be not contacted with oily hand.
14.7	Necessary precautions should be taken against electrical and gas leakage.
14.8	Non-deformed hoses should be used.

Table J.1: Recommendations to construction safety professionals (full list) (Cont'd)

14.9	Welders should possess license/certificate.
14.10	Proper personal protective equipment (PPE) should be used.
15)	**DEMOLITION WORKS**
15.1	Preparation and planning of actions should be performed before the start of demolition works.
15.2	Demolition area should be enclosed and warning signs are placed.
15.3	Existing service lines (gas, water, electricity lines, etc.) should be taken under control or cut where necessary.
15.4	Demolition works should be performed under the supervision of competent person.
15.5	People, vehicles, materials and equipment should be removed enough from the demolition area.
15.6	Necessary precautions should be taken to avoid dust during demolition.
15.7	Materials and ruins should be transported in a systematical and secured way.
15.8	Asbestos powder measurement should be performed for structures that may contain asbestos.
15.9	Proper personal protective equipment (PPE) should be used.
16)	**WORKERS**
16.1	Workers should not avoid the use of personal protective equipment intentionally.
16.2	Workers should not take the apparent risks.
16.3	Workers should perform correct methods and applications.
16.4	Workers should perform their job with plan and cautiousness.
16.5	Workers should have safety consciousness.
16.6	Workers should perform their job with morale.
16.7	Workers should not perform their jobs without permission.
16.8	Workers should not use alcohol or drug.
16.9	Workers should not change continuously (Personnel turnover rate is low.).
16.10	Adequate safety trainings should be supplied to workers.

CURRICULUM VITAE

PERSONAL INFORMATION

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EDUCATION

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M.S.	Middle East Technical University	2010
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PROFESSIONAL EXPERIENCE

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2011-Present	BOTAŞ GENERAL DIRECTORATE	Prj. Controls Manager
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2007-2008	TÜRK TELEKOM G. D.	Civil Engineer
2005-2007	BOTAŞ GENERAL DIRECTORATE	Civil Engineer
2003-2003	GAMA-TEKFEN-TOKAR J.V.	Trainee
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PUBLICATIONS

Gündüz, M., Nielsen, Y., and Özdemir, M. (2013). “A fuzzy assessment model to estimate the probability of delay in Turkish construction projects.” *Journal of Management in Engineering,* 10.1061/(ASCE)ME.1943-5479.0000261, 04014055.

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